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GEOLOGIC FEATURES OF TIN DEPOSITS.

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Numbers refer to districts indicated on map.

Europe.

1. Cornwall, England.
2. Devonshire, England.
3. Ross-Shire, Scotland.
4. Erzgebirge, Germany.
5. Brittany, France.
6. Central Plateau, France.
7. Tras-os-montes, Portugal.
8. Galicia, Spain.
9. Campiglia Marittima, Italy.
10. Pitkäranta, Finland.

Asia.

11. Malay States.
12. Banka and Billiton.
13. Sumatra.
14. Bungo Prov., Japan.
15. Satsuma Prov., Japan.
16. Mergui, Burma.
17. Tavoy, Burma.
18. Siam.
19. Yunnan, China.
20. Transbaikal, Siberia.

Africa.

21. Transvaal, South Africa.
22. Swazieland, South Africa.
23. Cape Colony, South Africa.
24. Belgian Congo.
25. Nigeria.

Australia.

26. Stanthorpe, Queensland.
27. Heberton, Queensland.
28. Greenbushes, W. Austr.
29. New England, N. S. W.
30. Mt. Bischoff, Tasmania.
31. Blue Tier, Tasmania.
32. Heemskirk, Tasmania.

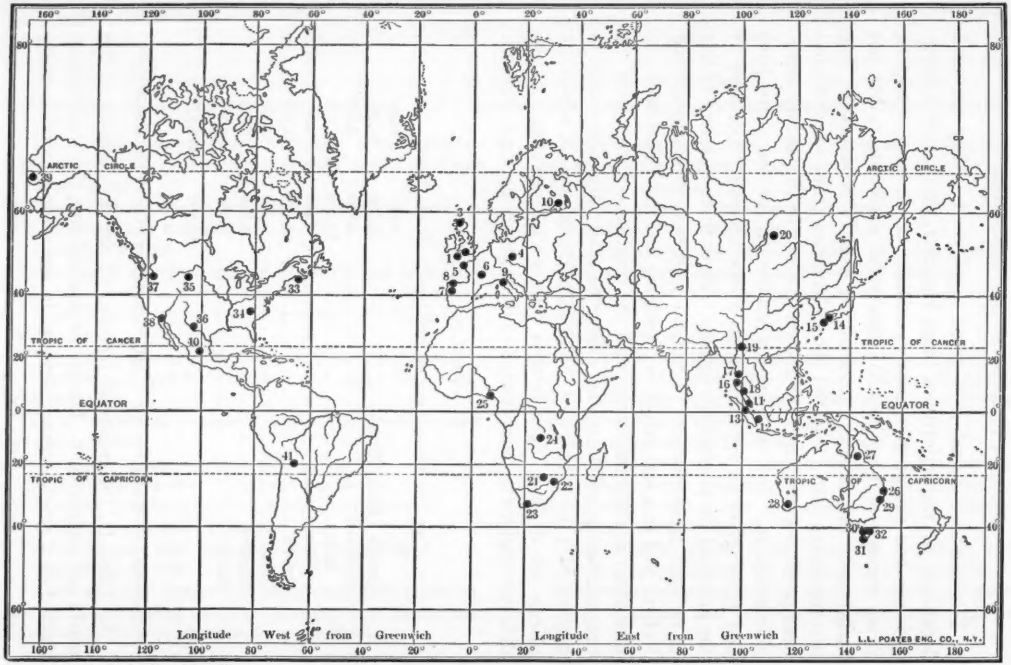
North and South America.

33. Nova Scotia.
34. North and South Carolina.
35. Black Hills, South Dakota.
36. Franklin Mts., Texas.
37. Spokane, Wash.
38. Temescal, Cal.
39. Cape York, Alaska.
40. Mexico.
41. Bolivia.

INTRODUCTION.

In presenting this summary of the geologic features of tin deposits to the readers of ECONOMIC GEOLOGY, the writers have endeavored to establish criteria which may prove of value to mining engineers and geologists.

From time to time papers have appeared dealing with the economic geology and genesis of tin in individual regions. In some of these comparisons are drawn between different districts, but, as far as the present writers are aware, there has yet appeared no summary of the generalities of the geologic occurrence of tin, nor has the available data been assembled in convenient form. Since it is obviously impossible, in a short paper, to embody detailed descriptions of the various occurrences of tin, only the more striking geologic features have been summarized in the following pages. It is believed that the inferences which may be drawn from these warrant their presentation.



From McKinley's Outline Map No. 201.

FIG. 18. Map showing the distribution of tin deposits.

PRODUCTION AND DISTRIBUTION.

Tin has been found in a great number of widely scattered localities. In the majority of these, however, production is insignificant, and the greater number contain tin in small amounts, often enough to give hope of successful exploitation, but not sufficient to influence the total of the world's production. The accompanying map (Fig. 18) shows localities from which tin has been produced or where it is known to occur in supposedly workable amounts. The table of tin production for the years 1910 and 1911[1] gives an approximation of the relative importance of the principal tin-producing regions. About three quarters of this is derived from placers. Lode tin is mined in Cornwall and Bolivia, and to a less extent in Tasmania and the Transvaal. As this paper is concerned only with the original occurrence of the ore, no attempt will be made to describe placer deposits, except in dealing with the geology of the original deposits from which the placers are derived. The relative commercial importance of the different regions is subordinated to their purely geologic features.

TABLE I.

THE TIN PRODUCTION OF THE WORLD (LONG TONS).

	1910.	1911.
Straits (Malay States)	54,600	55,265
Australia	4,650	4,140
Banca	13,500	15,131
Billiton	2,200	2,200
Bolivia	17,550	22,500
China	2,200	2,500
England	5,800	5,800
Sundry	3,000	3,000
	103,500	110,536

SALIENT FEATURES OF THE GEOLOGY OF TIN REGIONS

In Table II. the principal features of the tin deposits of the world are summarized. Under the first column, the writers have treated as a single region, deposits in the same general locality,

[1] *Min. and Sci. Press*, Vol. 104, p. 70 (1912).

TABLE II.

THE PRINCIPAL TIN DISTRICTS OF THE WORLD.

No.	1 District.	2 Principal Intrusive.	3 Associated Dikes.	4 Invaded Rocks.	5 Age.	6 Type of Original Occurrence.	7 Associated Metals.	8 Authorities.

TABLE II.

THE PRINCIPAL TIN DISTRICTS OF THE WORLD.

No.	1 District.	2 Principal Intrusive.	3 Associated Dikes.	4 Invaded Rocks.	5 Age.	6 Type of Original Occurrence.	7 Associated Metals.	8 Authorities.
1	*Cornwall*	Granite[1]	Quartz porphyry[2]	Slate (Killas)	Post-Carboniferous and pre-Triassic	Veins, lode fissures and stockworks	Cu, Wo, (Pb, Ag)	46, 58, 79
2	Devonshire	Granite	Quartz porphyry	Slate, diabase and limestone	Same as 1	Contact metamorphic		16
3	Rosshire[3]	Granite-gneiss				Magmatic segregation	Fe	36
4	*Erzgebirge*	Granite[4]	Granite, quartz porphyry	Slate, schist and older quartz porphyry	Permo-Carboniferous	Stockworks and veins	Wo, Bi, Mo, As, Co, Pb, Ag	25, 26, 27, 28, 29, 81, 82, 60
5	Brittany, France	Granulite	Granulite dikes	Schist	Probably same as 1	Stockworks		37
6	Central Plateau, France	Granulite[5]	Quartz porphyry and pegmatite	Gneiss and older granite		Veins and stockworks		37, 34.
7	Tras-os-Montes, Portugal	Granite		Slate		Stockworks and veins		34
8	Galicia, Spain	Granulite	Granulite porphyry	Schist		Veins	Wo	34, 37.
9	Campiglia Marittima	Granite[6]	Quartz porphyry[7]	Limestone	Tertiary	Replacement deposit	Fe, Pb, Zn	24, 12, 72
10	Pitkäranta Finland	Granite[8]	Aplite	"Skarn" and earlier pegmatite	Late pre-Cambrian		Cu, Zn, Fe	84
11	*Malay States* (P)	Granite[9]	Pegmatite	Limestone and schist	Post-Triassic and pre-Eocene[10]	Fissure veins and pegmatites	Wo	67, 80, 100, 76, 80a
12	*Banka and Billiton* (P)	Granite	Granite porphyry, quartz porphyry and aplite	Slate and sandstone	Early Paleozoic or later[11]	Veins	(Fe)	6, 89
13	*Sumatra* (P)	Granite[12]		Sandstone		Veins		74
14	*Bungo Prov.* (P) Japan	Granite	Quartz porphyry	Limestone	Paleczoic[11]			102, 49
15	*Satsuma Prov.*, Japan	Augite andesite dikes		Sandstone	Mesozoic or Tertiary	Veins	Cu	102, 49
16	*Mergui, Burma* (P)	Granite	Pegmatite and quartz porphyry	Schist, slate and sandstone	Paleozoic	Segregations		47
17	Tavoy, Burma (P)	Granite			Paleozoic[11]			47
18	*Siam* (P)							34
19	*Yunnan* (P)	Granite	Pegmatite		Triassic or later[11]			34
20	Transbaikal	Granite				Veins		34
21	*Transvaal*[13]	Granite[14]	Quartz porphyry, aplite and peg-	Felsite, shale and quartzite	End of Lower Waterburg	Veins, pegmatites, pipes and		8, 56, 59, 93

19	*Yunnan* (P)	Granite	Pegmatite		Triassic or later[17]			34
20	Transbaikal	Granite				Veins		34
21	*Transvaal*[13]	Granite[14]	Quartz porphyry, aplite and pegmatite	Felsite, shale and quartzite	End of Lower Waterburg	Veins, pegmatites, pipes and greisen		8, 56, 59, 93
22	Swazieland (P)	Granite	Pegmatite, aplite and quartz porphyry[15]	Schist		Pegmatite		59, 77, 93
23	Cape Colony	Granite				Veins		77, 34
24	Congo (P)	Granite[16]		Mica schist, slate and quartzite	Post-Silurian	Veins		5, 34
25	*Nigeria* (P)	Granite		Gneiss				34
26	*Stanthorpe* (P) Queensland	Granite		Altered sediments		Veins and pegmatite		4
27	*Heberton*, Queensland	Granite[17]	Eurite and granite	Quartzite, graywacke, slate, gneiss and schist	Post-Carboniferous	Lode and stockwork		17, 31
28	*West Australia* (P)	Granite	Granite and pegmatite dikes	Gneiss and greenstone		Lode fissure, and greisen		55, 99, 34
29	*New England*, New South Wales	Granite[18]	Quartz porphyry and pegmatite	Older granite and slate	Probably Permian	Veins, pipes and greisen	Cu, Pb, Ag, Mo	21, 22, 23, 31, 69
30	*Mt. Bischoff* (P) Tasmania	Quartz porphyry and eurite dikes		Schist	Post-Silurian	Greisen		35, 40, 34, 54
31	*Heemskirk*,[19] Tasmania	Granite[20]	Granite porphyry, quartz porphyry and aplite	Slate and sandstone	Devonian	Veins	Cu, Pb, Ag, Zn	94, 95, 96, 85, 87
32	*Blue Tier*, Tasmania	Granite[21]				Greisen		34
33	Nova Scotia	Granite[22]	Pegmatite	Slate and sandstone	Devonian	Pegmatite	Wo, Mn	33
34	N. and S. Carolina	Granite[23]	Pegmatite	Gneiss and schist	Archean[24]	Pegmatite		38, 39, 71
35	*Black Hills*	Granite[25]	Pegmatite	Schist	Algonkian	Pegmatite and veins	Wo, Ta	15, 18, 44, 50, 66
36	Franklin Mts., Texas	Granite[26]	Aplite	Limestone and quartz-porphyry	Post-Paleozoic	Veins and greisen		73, 97
37	Spokane, Wash.	Granite[27]	Pegmatite	Gneiss, quartzite and schist	Probably Archean	Pegmatite	Wo, (Pb, Ag)	20
38	Temescal, Cal.	Granite	Porphyry and aplite	Quartzite and schist	Post-Carboniferous	Veins		11, 32
39	*Cape York* (P) Alaska	Granite[28]	Quartz augite porphyry	Limestone, slate and schist	Post-Mississippian	Veins		19, 52, 53
40	*Mexico*	Rhyolite			Late Tertiary	Veins	Bi	0, 41, 48, 65, 98
41	*Bolivia*	Granite	Granite-, quartz- and rhyolite-porphyry	Quartzite and schist	Mesozoic	Veins	Bi, Ag	1, 2, 3, 78, 83

Numbers refer to map (Fig. 1.), Nos. 1–10 Europe, 11–20 Asia, 21–25 Africa, 25–32 Australia, 33–41 North America.
Italics indicate that the district is a producer. "P" indicates that placer deposits are the most important commercially.

[1] Porphyritic muscovite-biotite granite with orthoclase

[15] Quartz porphyry composed of feldspar, quartz, mica

			lite		schist	ferous		
39	*Cape York* (P) Alaska	Granite[28]	Quartz augite porphyry	Limestone, slate and schist	Post-Mississippian	Veins		19, 52, 53
40	*Mexico*	Rhyolite			Late Tertiary	Veins	Bi	0, 41, 48, 65, 98
41	*Bolivia*	Granite	Granite-, quartz- and rhyolite-porphyry	Quartzite and schist	Mesozoic	Veins	Bi, Ag	1, 2, 3, 78, 83

Numbers refer to map (Fig. 1.), Nos. 1–10 Europe, 11–20 Asia, 21–25 Africa, 25–32 Australia, 33–41 North America.

Italics indicate that the district is a producer. "P" indicates that placer deposits are the most important commercially.

[1] Porphyritic muscovite-biotite granite with orthoclase phenocrysts. Tourmaline, apatite, andalusite and zircon are accessories.

[2] Elvan contains quartz, orthoclase, biotite and occasionally muscovite and tourmaline.

[3] Dartmoor Forest.

[4] Porphyritic granite composed of quartz and orthoclase, with plagioclase low in lime, and dark-colored lithia mica.

[5] Porphyritic quartz-orthoclase granite, containing muscovite.

[6] Tourmaline granite. Occurs 2.5 km. from the deposit.

[7] Composed of quartz, orthoclase and muscovite; cordierite accessory.

[8] Often porphyritic, contains orthoclase, smoky quartz and rarely biotite.

[9] Often porphyritic, contains quartz, feldspar and biotite or hornblende (or both). Tourmaline accessory.

[10] Probably post-Inferior Oölyte and pre-Eocene.

[11] Probably same age as Malay States.

[12] Albite granite with muscovite and tourmaline.

[13] Waterburg district.

[14] "Red granite," fine to medium grained biotite granite, grading toward aplite, often porphyritic, with quartz and orthoclase in graphic sturcture in groundmass.

[15] Quartz porphyry composed of feldspar, quartz, mica and hornblende, with cassiterite, garnet, monazite and tourmaline as accessories.

[16] Biotite granite, containing tourmaline.

[17] Hornblende-biotite granite.

[18] Quartz, albite, orthoclase and biotite in order named.

[19] Zeehan, North Dundas and Heemskirk districts.

[20] Coarse grained biotite granite, locally contains tourmaline.

[21] Porphyritic biotite granite.

[22] Light-colored muscovite granite.

[23] Contains chiefly quartz, feldspar (principally microcline) and muscovite. Minor constituents are biotite, garnet, zircon and apatite.

[24] Mentioned in (*44*) as of late Paleozoic age.

[25] Chief constituents are quartz, orthoclase and muscovite.

[26] Contains much anhedral quartz and feldspar (largely microperthite) and a few grains of microcline. Biotite subordinate, hornblende rare.

[27] Composed of quartz, biotite and both orthoclase and plagioclase, approximately the composition of monzonite.

[28] Quartzose orthoclase granite, with subordinate amounts of sodic oligoclase and biotite, prevailingly porphyritic in habit.

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whose major features of occurrence are closely related. For instance, no sub-division of such districts as Cornwall or the Erzgebirge is attempted. The second, third, fourth and fifth columns are largely self-explanatory. Where descriptions of the principal intrusives are available, they have been summarized in the footnotes. In the fifth column, the age of the deposit has been entered wherever it could be obtained from the descriptions. In a few cases, inferences drawn by the present writers have been placed in footnotes. The "Other Deposits" in column 7, include not only important ores closely associated with the tin deposits themselves, but ore deposits, such as the lead-silver veins of Cornwall, which occur in the same general locality and are genetically more or less closely connected with the tin deposits. In the last column, under "References" the numbers given refer to papers which have been consulted in the preparation of this article, the titles of which will be found in the bibliography on page 257.

The generalizations which follow are based on data collected from descriptions of 41 districts.

ASSOCIATED ROCKS.

The most striking geologic feature of tin deposits is their very general association with acid intrusives. In nearly every case the deposits are to be found either in the near neighborhood of granite or actually in a granite country rock. This granite in all cases forms an intrusive body or bodies which are later than the surrounding rocks and whose intrusion has immediately preceded the mineralization.

Geologic Age.—The geologic age of the intrusives and the deposits dependent upon them is often impossible of close determination. The age of tin deposits ranges from Archean to late Tertiary. The periods of igneous intrusion at the close of the Carboniferous and during Mesozoic times seem to have been particularly favorable for the tin-bearing granites.

Form of Intrusion.—Although the intrusive granite some-

times occurs in dikes, it is most commonly in the form of a batholith, that is, a vast irregular body, having indefinite downward extension. These batholiths were intruded under a heavy cover, and their surface area therefore varies with the amount of erosion and the original irregularity of their upper surfaces. It is a characteristic of the batholithic method of intrusion that the dips of the contact should show great local variations. Where erosion has reached only the higher portions of the granite, disconnected areas may be exposed, implying a fairly flat upper surface of the intrusion as a whole. Also the width of the metamorphic aureole is roughly proportional to the flatness of dip. As will be brought out in detail in another place, it appears to be an essential feature of tin occurrence that the cover, at least in the immediate vicinity of the deposits, should not be greatly eroded. It therefore often happens that the granite in many tin districts appears as a series of bosses, more or less widely separated at the surface, but probably uniting at depth, as in Cornwall. In a few cases a large surface is exposed. In Finland, the so-called Rapikiwi granite outcrops over an immense area and in the Malay States, the granite occupies the major portion of the mountain ranges.

Petrographic and Chemical Character.—Good petrographic descriptions of the granite and accompanying dike rocks are scarce, as microscopic study has been made in comparatively few localities. In many of the papers consulted the parent rock is simply called granite, without further description.

Granites associated with tin ores are often porphyritic in texture, as might be expected at the margins of any batholith. Orthoclase is always prominent, and usually the most prominent feldspar, often giving a red color to the granite, while acid plagioclase, most commonly oligoclase, is present in varying amounts. In the New South Wales granite alone, does plagioclase appear to exceed the orthoclase. Of the dark silicates, biotite is more common than hornblende but both occur in several cases. Tourmaline and topaz are frequent as accessories, but are not always

present. Muscovite is likewise a common accessory but as it is most prominent where the granite has been altered by pneumatolytic action, it is probably more often a secondary mineral.

Table III. shows analyses of granite and quartz porphyry from tin-producing regions. From these it may be seen that the granites associated with tin deposits are alkaline in type, the percentages of lime and magnesia being abnormally low and the content of the alkalies rather high. With one exception the content of K_2O is greater than that of Na_2O. Under each analysis is given the classification of the rock according to the Quantitative System. While there is an apparent wide variety as to their names (eight varieties out of eleven analyses) in reality they are grouped fairly closely in the alkalic rangs and the dopotassic and sodipotassic subrangs.

In general there is not much in either the mineralogical or chemical nature of these granites to distinguish them from non-stanniferous varieties.

The acid dikes which accompany the granites may be arbitrarily divided into quartz porphyries, pegmatites and aplites. Tin-bearing quartz veins might well be included here also, but the discussion of these will be reserved for the latter portion of this paper. To the first group belong rocks of the general type of the elvans of Cornwall. These include granite porphyry, differing slightly from the parent granite, eurite, a quartz-feldspar rock, and quartz porphyry. Here also should be included the rhyolite dikes mentioned by Armas (1, 2, 3) in connection with certain of the Bolivian deposits. Mineralogically the porphyries are not greatly different from the parent granite, though pneumatolytic minerals such as tourmaline, muscovite and topaz are more prominent. These increase in abundance as the rock grades toward a pegmatite. In chemical composition the quartz porphyries appear to be slightly more acid than the neighboring granite, but otherwise very similar.

Aplites consisting essentially of quartz, orthoclase and muscovite often accompany the granite, but pegmatites are more com-

TABLE III.

ANALYSES OF GRANITES AND QUARTZ-PORPHYRIES FROM TIN-PRODUCING REGIONS.

	A	*B*	*C*	*D*	*E*	*F*	*G*
SiO_2	72.84	72.05	74.69	74.54	70.65	72.88	71.46
Al_2O_3	16.25	15.83	16.21	14.86	16.16	14.47	15.38
Fe_2O_3	0.14	0.39	tr.	2.53	1.53	——	0.30
FeO	1.49	1.50	1.16	0.23	0.52	2.45	2.27
MgO	0.55	0.51	0.48	tr.	tr.	tr.	0.47
CaO	1.10	1.14	0.28	0.29	0.55	0.10	0.22
Na_2O	2.25	2.65	1.18	3.49	0.54	} 7.15	2.79
K_2O	5.19	4.79	3.64	3.73	8.66	}	5.51
H_2O+	} 0.63	0.64	0.34	} 0.87	1.22		} 1.70
H_2O-			0.89				
MnO			0.58	tr.		0.82	tr.
LiO_2			0.10	tr.		tr.	
TiO_2							
SnO_2							
P_2O_5							
Total	100.44	99.50	99.55	100.54	99.83	100.15	100.10
Sp. Gr.				2.66	2.62		
Class	I. Persalane	I. Persalane	I. Persalane	I. Persalane	I. Persalane		I. Persalane
Order	3. Quarfelic	3. Quarfelic	3. Quarfelic	3. Quarfelic	4. Quardofelic		4. Quardofelic
Rang	2. Domalkalic	2. Domalkalic	1. Peralkalic	1. Peralkalic	1. Peralkalic		1. Peralkalic
Sub-rang.	3. Sodipotassic	3. Sodipotassic	2. Dopotassic	3. Sodipotassic	1. Perpotassic		2. Dopotassic
Name	Tehamose	Tehamose	Magdeburgose	Alaskose	Lebachose		Omeose

A. Granite (Carn Menellis) Penryn, Cornwall. (*46*, p. 60.)
B. Granite (Carn Menellis) Carnsew, Cornwall. (*46*, p. 60.)
C. Granite, Carn Brea, Cornwall. (*46*, p. 63.)
D. Granite, Botallach, Cornwall. (*96a*, p. 126.)
E. Granite, Chywoon Morvah, Cornwall. (*96a*, p. 142.)
F. Elvan, Truro, Cornwall. (*46*, p. 74.)
G. Elvan, Mellanear, Cornwall. Quoted by Geikie, "Text-book of Geology," p. 209.

	H	*I*	*J*	*K*	*L*	*M*	*N*
SiO_2	74.68	74.03	75.31	70.93	76.69	79.69	73.76
Al_2O_3	12.73	13.87	13.23	16.38	10.89	13.49	
Fe_2O_3	——	0.09	1.50	0.36	0.76	0.14	
FeO	3.00	0.95	n.d.		0.39	2.08	
MgO	0.35	0.15	0.25	0.58	0.18	0.60	
CaO	0.09	0.30	0.65	0.32	1.73	0.46	0.81
Na_2O	1.54	3.71	2.60	4.52	5.35	0.08	3.64
K_2O	4.64	6.14	5.51	5.47	2.97	2.71	5.66
H_2O+	1.17	1.17	0.86	1.50	0.13	n.d.	
H_2O-		——			0.37		
MnO							
LiO_2		tr.					
TiO_2	0.71	tr.					
SnO_2	0.09						
P_2O_5		0.27					
Total	99.50	100.68	99.91	100.06	99.46	99.31	
Sp. Gr.		2.662					
Class	I. Persalane	I. Persalane	I. Persalane	I. Persalane	II. Dosalane	I. Persalane	
Order	3. Quarfelic	4. Quardofelic	3. Quarfelic	4. Quardofelic	4. Quardofelic	3. Quarfelic	
Rang	2. Domalkalic	1. Peralkalic	1. Peralkalic	1. Peralkalic	1. Peralkalic	1. Peralkalic	
Sub-rang	2. Dopotassic	3. Sodipotassic	3. Sodipotassic	3. Sodipotassic	4. Dosodic	3. Sodipotassic	
Name	Mihalose	Liparose	Alaskose	Liparose	Pantellerose	Alaskose	

H. Granite, Altenberg, Saxony. (*14*, vol. 2, p. 411.)
I. Granite, Kleiner Komberg, Erzgebirge. (*96a*, p. 153.)
J. Granite, Johanngeorgenstadt, Saxony. (*96b*, p. 22.)
K. Quartz porphyry, Campiglia Marittima, Italy. (*72*, p. 328.)
L. Granite, New England, New South Wales. (*21*, p. 225.)
M. Quartz porphyry, Mt. Bischoff, Tasmania. (*40*, vol. 39, p. 80.)
N. Granite, El Paso, Texas. (Partial analysis.) (*73*, p. 147.)

mon. The pegmatites associated with tin deposits are particularly rich in pneumatolytic minerals, especially those containing fluorine and boron. The following list of minerals from a tin-bearing pegmatite at New Ross, Nova Scotia (33, p. 82), shows the mineralogical complexity of these rocks. Cassiterite, monazite, columbite, durangite, amblygonite, lepidolite, wolframite, scheelite, hübnerite, molybdenite, sphalerite, beryl, apatite, tourmaline, fluorite, pyrolusite, manganite, hematite, magnetite, siderite, kaolin, quartz (crystals up to 27 inches in length) and feldspar.

Rocks of the type of the Cornwall luxullianite belong, not to the pegmatites, but to the pneumatolytic modifications of the granite, which will be later discussed. Gradations between pegmatites and quartz veins are not uncommon; for example the Luxer vein in the Erzgebirge (81, p. 176) with a gangue of quartz, orthoclase, albite and fluorite, and the stanniferous quartz segregations of Burma (47, p. 205).

The basic derivatives of the granite magma are of no importance in connection with the tin deposits. Minette dikes are mentioned in descriptions of several regions and several of the granite batholiths have dioritic phases.

APPARENT EXCEPTIONS TO THE ASSOCIATION OF TIN WITH GRANITIC INTRUSIVES.

Certain tin deposits in Mexico, of small commercial importance, are associated with Tertiary rhyolites. The cassiterite occurs in association with such minerals as topaz, durangite, quartz, feldspar, wolframite and hematite and also chalcedony and opal, in joint cracks and irregularly disseminated through the rhyolites and rhyolitic tuffs. The presence of pneumatolytic minerals under such conditions is not of itself exceptional as Zirkel (101, Vol. 2, p. 235) and Rosenbusch (75, p. 154) cite the following minerals as known to occur in rhyolites: tourmaline, topaz, garnet, cordierite. It is therefore probable that the minerals of these deposits were formed by the after-action of the acid extract of the rhyolite magma in much the same way that the more

usual type of tin deposit is formed by mineralizers coming from the chemically similar granite magma. Hence the Mexican deposits do not absolutely contravene the law of association of tin with granite. There is moreover nothing impossible in the formation of cassiterite at surface temperatures and pressures, as is shown by the presence of this mineral in various siliceous sinters and of SnO_2 in the waters of certain thermal springs.

The Taniyama Mine (**102**, p. 183) in the Satsuma province, Japan, appears to offer an example of a tin deposit not in association with granitic rocks. Here the country rock consists of Mesozoic slate and sandstone cut by dikes of augite andesite. The ore consists of cassiterite, galena, pyrite, blende and rarely wolframite, in a quartz gangue. No mention is made of any granite in the neighborhood. The information in regard to this deposit is so scanty, however, that it is not impossible that there may be some explanation of this apparently anomalous occurrence.

The Bolivian deposits have been generally supposed to occur in connection with andesite and hence to be an exception to the rule of association of tin with granitic intrusives. Recent papers by Rumbold (**78**) and Armas (**1, 2, 3**), however, seem to show that tin occurs in connection with quartz porphyry and intrusive rhyolite. Granite has also been found in several localities.

INVADED ROCKS.

Table II., column 4, shows the rock invaded by the intrusive. Schist is mentioned 16 times, slate 11, quartzite 7, sandstone 6, shale 2, limestone 6, gneiss 6, older granites 3, and other igneous rocks 4. The variety here recorded shows that the invaded rock has no effect on the production of tin deposits. A possible influence might be exerted by the chemical nature of the enclosing rock. Thus in a rock easily attacked by the pneumatolytic vapors, such as an impure limestone, there would be formed a contact zone of minerals resulting from the reaction of the magmatic vapors on the rock. In so far as this zone tended

to use up the mineralizers in forming new minerals such an invaded rock might have an unfavorable influence on the formation of ore deposits. However, even in exceptional circumstances, as in the case of the Alaskan deposits, this zone of magmatic accessions does not extend far from the contact.

Contact Metamorphic Effects.—The changes in the invaded rock due to heat alone are not in any way different from those caused by nonstanniferous granitic intrusions. The chemical alteration produced by the mineralizing vapors and solutions emanating from the magma is also similar to that resulting from the ordinary granitic intrusion, except that in the greisen-like replacement of the invaded rock along the walls of a fissure, cassiterite may be introduced. An exceptional case is the deposit of Ear Mountain, Alaska (**52**, p. 29), where the limestone for a short distance from the granite is altered to a lime silicate rock, which by its richness in such minerals as tourmaline, axinite, ludwigite and boron-bearing vesuvianite, together with metallic sulphides, shows unusual accessions from the magma. A small amount of cassiterite and the tin-bearing borates, hulsite and pageite, are also found in this hornfels. The presence of cassiterite and the tin borates shows that the vapors which altered the limestone were not essentially different from those which formed the tin lodes.

THE TIN DEPOSITS.

FORMS OF DEPOSITS.

The approximate frequency of occurrence of different forms of tin deposits is shown in the following table.

Lodes	Normal lodes	27
	Pegmatitic lodes	7
Stockworks		12
Pipes		2
Segregations		2

Although a variety of forms are known, the majority of deposits, aside from placers, are confined to two types, lodes and stockworks. The veins and lode fissures are more important both

commercially and numerically than the stockworks, while the pipes and segregations are in most cases of greater geologic than commercial interest. The deposits in pegmatite dikes are not generally favorable for profitable exploitation but in some regions are the sources of important placer deposits.

Normal Lodes.—Under this heading are included both lode fissures and veins. By lode fissure is meant (51, p. 16) a series of parallel, closely spaced fissures, usually narrow, including tabular plates of country rock which is often completely replaced, resulting in a solid tabular mass of ore. The Cornish lode deposits are typical of many others. Often the ore occurs as an impregnation of the country rock bordering a fissure or zone of closely parallel fissures, with the development of occasional abnormal masses known as "carbonas." The impregnation and replacement of the country rock extends from a few inches to a foot or more on either side of an individual fissure, but in the case of lode fissures the ore bodies may reach a width of several feet. Other Cornish types are simple banded veins showing comby structure of the quartz in their central portions. More important, however, are the mineralized zones of brecciated country rock, or "crush conglomerate," which in some of the more important mines in the Camborne and Redruth district attain a width of "several fathoms" (58, p. 371). The fissures are most common near the margins of the granite masses and constitute a conjugate system in which they intersect in dip. In general the strike is parallel to the granite contact and the dip is either normal or approximately parallel to it. Another system of cross-courses cuts the main lodes in strike but are of minor importance. Tin veins are also important in the Zinnwald district of the Erzgebirge. Here they are grouped about the borders of a small granite stock and form two intersecting fissure systems, one flat and the other vertical. The filling of the one system passes into the filling of the other at the intersections, showing them to be contemporaneous. They are, however, cut and slightly faulted by a later system of fissures. The flat veins (Flötze) are approximately parallel to the gently dipping granite

mass and their width ranges from 6 inches to 6 feet. The vertical veins seldom exceed 8 inches in width. Crustified vein fillings of the banded type occur in Tasmania. Well defined veins are likewise characteristic of a number of districts, especially New South Wales and Bolivia.

Pegmatitic Lodes.—Cassiterite in pegmatite usually occurs as an original mineral. The deposits of North and South Carolina (39, p. 34) are examples of cassiterite as an original mineral constituent in pegmatite. The dikes consist of irregular disconnected pegmatitic masses, exhibiting great variations in strike, dip, width and extent. They range from small streaks a few millimeters wide to bands of 30 feet or more. The tin is usually concentrated along certain lines or zones in the dikes giving rise to very irregular ore shoots with occasional lens-like portions of greater width. In some places these shoots occupy the full width of the dike. Other similar pegmatitic lodes are those of the Black Hills, Vegetable Creek District, New South Wales, and Swazieland.

Stockworks.—The typical stockwork consists of a mass of rock traversed by a network of small veins, interlacing with one another and traversing the rock in various directions. The ore is not confined to the veins alone, but impregnates the intervening country rock as well. The mass is irregular in outline, merging into the country rock, and the boundaries are fixed by the limits of profitable exploitation. Such a group of fissures with the intervening granite altered to greisen and impregnated with ore is the "Altenberger Zwitterstock" of the Erzgebirge. Similar stockworks are mined in Cornwall, in both the granite and slates (killas), but are not the most important type of deposit. Stockworks are also important in New South Wales, Tasmania and South Africa.

Pipes.—Some interesting though less commercially important types of deposits are the "pipes" which have been described from the Transvaal and New South Wales. These are roughly cylindrical in shape and have their central portions filled with highly altered granite containing disseminated cassiterite, sur-

rounded by zones of cassiterite and tourmaline rock. They vary from 2 to 12 feet in diameter and penetrate the granite at high angles to depths of from 20 to over 500 feet. These pipes occur in granite and are often completely isolated from any line of fissuring or zone of weakness. In a few cases, however, they follow a definite line of fracturing and give a gradation from true pipes to intermediate forms of lenticular ore bodies. Such gradations are more pronounced in the Transvaal than in New South Wales. For the Transvaal pipes, Kynaston and Mellor (**56**, p. 103) suggest that "they were in all probability formed in an originally deep seated portion of the granite, which although practically consolidated was still doubtless at a very high temperature, and probably at that time had not undergone fissuring to any great extent. Relief of pressure, however, consequent upon the formation of fissures at higher levels, may have initiated the release from the underlying magma of the metalliferous compounds, which would then have ascended in gaseous condition through a practically unfissured zone."

Segregations.—In the Mergui District, Burma (**47**, p. 205), cassiterite is associated with wolframite, chalcopyrite and pyrite in massive segregations of quartz at the outskirts of a granite mass. A deposit in Ross-shire Scotland (**36**) consists of tin-bearing magnetite which, although the exact relationship is somewhat obscure, is believed to be a basic segregation in granite gneiss. If this is the case, it is the only deposit of its kind. The cassiterite is very irregularly distributed in the magnetite of the deposit, and is associated with feldspar, quartz, muscovite, biotite and rutile. No other minerals are found. Small particles of magnetite are also found as an original constituent disseminated throughout the main granite mass, but no cassiterite was found in a microscopic examination of this disseminated magnetite.

RELATIONS OF ORE BODIES TO INTRUSIVES.

Although in general not a contact-metamorphic mineral, cassiterite rarely migrates far from the granite contact. In Corn-

wall the lodes cut both the granite and slates but the tin is almost entirely confined to the granite. The same condition exists in the Transvaal (**56**, p. 45) where tin is found in the "Red Granite" and to some extent in the adjacent felsites and quartzites, but in almost every case the cassiterite deposits die out at short distances from the granite. An apparent exception is that of the Rooberg deposits in quartzite at a distance of 5 miles from the granite, but here the structure of the area indicates that the granite is continuous beneath the quartzite at no very great depth. In the New England District of New South Wales (**21**, p. 751) the tin invariably occurs in the "Acid Granite," in the adjacent country rock, or at the contact. The upward limit of the veins in the Vegetable Creek District in the same region is said to be the bottom of the slates and the top of the granite. The tin production of the Erzgebirge is largely from the greisenized granite. In the "Altenberger Zwitterstock" it is confined entirely to the granite and the same is in general true for the other districts except Sauberg, where the veins are in mica schist and no large mass of granite has been encountered. Here the presence of granite dikes in the workings indicates that a granite mass exists at no very great depth (**81**, p. 270).

Similar conditions prevail in other regions. In reviewing the literature the writers have found that in 26 cases the cassiterite occurs almost exclusively in the granite, while in 8 it is divided between the granite and invaded rock, and in only 4 is it preponderantly in the invaded rock. It is also found that tin deposits are generally lacking where the contact between the granite and invaded rock is steep but tend to occur in both the granite and overlying cover where the contact dips at a low angle.

RELATION OF EROSION TO DEPOSITS.

Wherever tin deposits accompany a batholithic intrusion of granite it has been found that the deposits occupy positions at or near the summit of the batholith. Hence the extent to which the granite has been eroded is a very significant factor. While none of the descriptions give any definite statement as to the amount of

cover eroded, it is not necessary to suppose that the mere presence of a granite batholith always implies excessive depth of consolidation. It has been shown for the Boulder batholith in Montana that at one place the thickness of the cover probably did not exceed some two thousand feet (**5a**, p. 166). Where denudation has exposed only the upper portion of the batholith, since deposits tend to accumulate in such upper portions, they may be looked for over any part of the exposed granite area in almost their original proportions. On the other hand, in regions where denudation has extended deeper into the batholith, it may be expected that deposits originally existing in the upper portions would be removed, perhaps to form placers, and that the central portions will contain only the stubs of the pre-existing veins or be altogether barren. In this case the probable position for a tin deposit would be near the border of the batholith. A series of geologic sections of various tin occurrences is given in Figs. 19–27, and brings out these relations very forcibly.

In the Redruth District of Cornwall erosion has cut deeply into the granite and no ore bodies are found in the central portion of the Carn Menellis granite mass nor on the eastern side of the granite where the dip of the contact is steep. (See Fig. 19.) The producing district is situated near the northern and western borders where the granite dips gently beneath the slate or where small outlying bosses are exposed. In the Erzgebirge (Fig. 20) the cassiterite is likewise confined to the upper portions of the granite mass. The Altenberg Zwitterstock extends to a distance of only about 750 feet below the outcrop while in the Zinnwald the veins die out at even shorter distances (**81**, p. 171). The same relation holds true for other districts in the region where the erosion of the granite has been slight (Figs. 21 and 22). The largest granite exposures, however, the Eibenstock and the Schellerhau, imply extensive denudation, and there are now no deposits in their central portions, although tin is mined at their margins. In Finland (Fig. 23) the deposits occur at a considerable distance horizontally from the granite but at no great height above it. Here again there has been con-

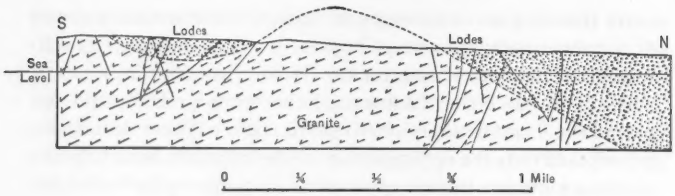

FIG. 19. Section from Feltrick to New North Pool, Cornwall. (Hill & McAlister *46*, p. 126.)

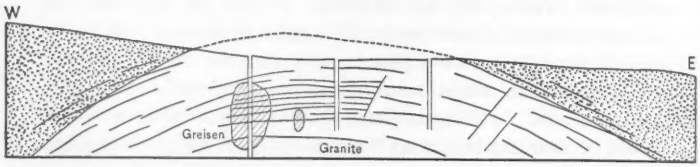

FIG. 20. Ideal section through Zinnwald granite. After Zinkeisen. (Beck *10*, Vol. I., p. 227.)

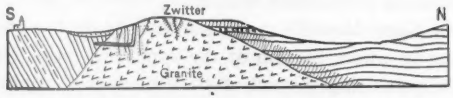

FIG. 21. Ideal section through Albertham in the Erzgebirge. (*10*, p. 627.)

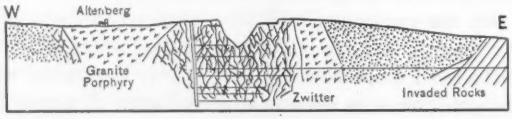

FIG. 22. Section through the Altenberg. (Dalmer *25*, p. 278.)

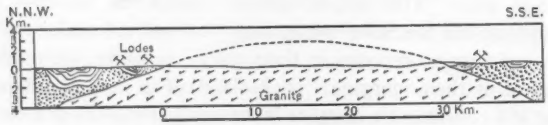

FIG. 23. Ideal section through the Rapikiwi granite batholith, Finland. (Trüstedt *84*, p. 93.)

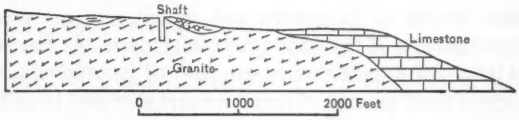

FIG. 24. Diagrammatic section, Ear Mt., Alaska. (Knopf *52*, p. 30.)

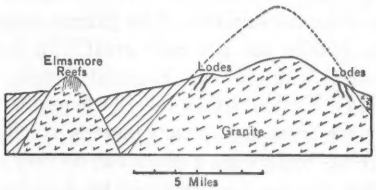

FIG. 25. New England District, New South Wales. (Cotton *22*, p. 133, dotted lines added by writers.)

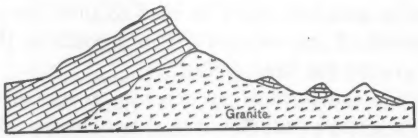

FIG. 26. Cross section of Franklin Mts., Texas, tin bearing granite. (Weed 97.)

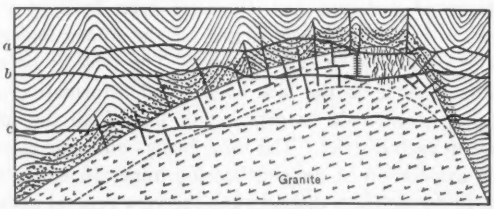

FIG. 27. Ideal section of tin bearing granite intrusion. Lines *a*, *b* and *c* represent successive erosion levels; *x*, metamorphic aureole; *y*, inner limit of mineralization.

siderable erosion of the granite and deposits are not found in the central portion of the Rapikiwi granite mass. At Ear Mountain, Alaska, the granite carries remnants of its original cover in the shape of small patches of limestone and slate and large blocks of limestone are found included in the granite (Fig. 24) (52, p. 25). In the Malay States, where cassiterite has been exploited in the central portions of the batholith, the remnants of the cover left as patches along the summits of the granite ranges show that erosion of the granite has not been great. In the deposits in the "Acid Granite" of the New England District, New South Wales (Fig. 25), Cotton states that "where the ore deposits occur at a distance from the contacts there is usually evidence to show that there has really been a contact at no very great vertical distance and that this has been removed by denudation" (22, p. 780). It is also true for this region that where the granite has suffered considerable denudation deposits are confined to the borders of the mass and are absent in the central portions.

Many other instances might be cited to show the very extensive application of this relation of tin deposits to the depth to which the granite has been eroded.

The position and form of tin deposits, in sucessive stages of erosion of a granite batholith are shown in the ideal section (Fig. 27).

MINERALOGICAL ASSOCIATIONS OF THE ORES.

In Table IV. the associations of minerals as given in the descriptions of different districts have been brought together to furnish a basis for a comparison of the mineralogical associations of cassiterite in each district. The table is necessarily approximate owing to the lack of detailed information and no attempt has been made to give a full list of all the minerals occurring in each district. The table brings out very clearly the universal association of fluorine-bearing minerals, either fluorite or topaz, in the different districts and the very general association of tourmaline, wolframite and molybdenite with cassiterite. Sulphides are commonly present in tin deposits, but the tin sulphide, stannite, is of comparatively rare occurrence. Associa-

TABLE IV.

MINERALOGICAL ASSOCIATIONS OF SOME OF THE MORE COMMON MINERALS IN TIN DEPOSITS.

	Bismuth.	Silver.	Galena.	Sphalerite.	Chalcopyrite.	Pyrite.	Arsenopyrite.	Pyrrhotite.	Stannite.	Fluorite.	Quartz.	Cassiterite.	Hematite.	Magnetite.	Siderite.	Topaz.	Chlorite.	Tourmaline.	Micas.	Feldspars.	Kaolinite.	Apatite.	Wolframite.	Scheelite.	Molybdenite.
Cornwall																									
Erzgebirge																									
Finland																									
Central Plateau (France)																									
Malay States																									
Banca and Billiton																									
Transvaal																									
Swazieland																									
Queensland																									
Tasmania (Zeehan)																									
(North Dundas)																									
(Mt. Bischoff)																									
New South Wales																									
Bolivia																									
Mexico																									
Alaska																									
Carolina																									
Black Hills																									
Nova Scotia																									
Campiglia Marittima (Tuscany)																									

tion of such minerals as molybdenite, pyrrhotite, magnetite, cassiterite, topaz, tourmaline and wolframite are generally considered as indicative of the pneumatolytic or deep vein zones.

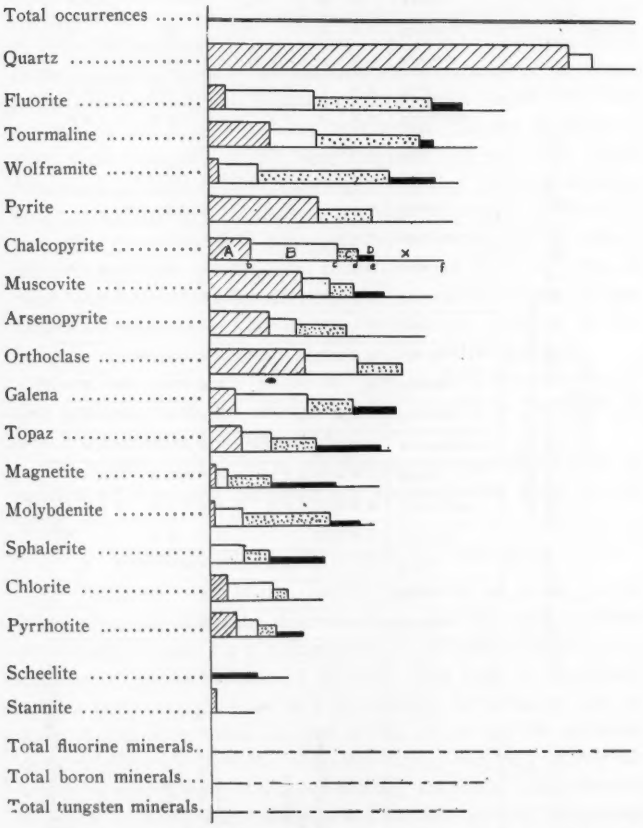

FIG. 28. Approximate quantitative distribution of the more important minerals associated with cassiterite. Length of line is proportional to the number of occurrences. Height represents relative abundance, A = very abundant, B = plentiful, C = prominent, D = rare, X = quantity unknown.

Fig. 28 gives a graphic representation of the quantitative distribution of some of the minerals found in tin deposits. The length of the lines is proportional to the number of occurrences of each mineral and the height represents their relative abundance. Where no vertical line is present the relative abundance is unknown. For example, the total number of occurrences of chalcopyrite in tin deposits is represented by the length of the line *a–f*; in the number represented by the line *a–b* it is a very abundant constituent (area *A*); and in the number represented by *d–e* it is rare (area *D*). The length of line *e–f* represents the number of occurrences in the descriptions of which chalcopyrite is mentioned as being a constituent of the deposit without any statement as to its abundance.

It thus appears that quartz, feldspar, mica, tourmaline, pyrite and arsenopyrite occur very abundantly in a number of deposits, while topaz, fluorite, pyrrhotite, pyrite and chlorite occur very abundantly in a less number of deposits (area *A*). In a large proportion of the deposits the minerals, wolframite, molybdenite, tourmaline, galena, chalcopyrite and fluorite most commonly occur in an abundance represented by the area *B*. The distribution and quantity of the remainder of the minerals are irregular. The lines at the foot of the table show the importance of fluorine as compared with boron and tungsten.

Other important though less widely distributed minerals of tin deposits are: ilmenite, beryl, spodumene, columbite, tantalite, danburite, triplite, heterosite, monazite, phenacite, axinite, durangite, aeschynite, and uraninite.

The tin lodes of the Black Hills are often cited as deposits not known to contain fluorine but triplite, a fluorine bearing mineral, is mentioned in a list of minerals from the Etta mine (**44**, p. 149). A tin deposit which apparently contains no fluorine bearing minerals is that of Campiglia Marittima, Italy (**12**, p. 135).

Ores in Close Association with Tin.—As shown by column 7 of Table II., tin is often associated with other ores. Of these copper is the most common, but silver, lead, bismuth, tungsten and molybdenum are often important.

In Cornwall, tin and copper occur together in intimate association, but in many cases occupy different horizons in the lodes, as in the Dolcoath mine. In this case, copper ore mixed with tin ore occupies the upper 200 fathoms of the lode, while the principal tin ore bodies lie below this. The upper part of this vein is in slate (killas) and the lower part in granite. In general the tin comes mainly from the granite, the copper mainly from the slates, and both tin and copper from the marginal areas. Lead and silver have also been mined in Cornwall, but although closely following the tin in time of deposition, occur outside the tin-copper areas. Copper is associated with the tin deposits of the New England District in New South Wales and the North Dundas and Zeehan fields of Tasmania. Lead and zinc ores are also associated with these deposits but occur beyond the zone of cassiterite veins. Dalmer (**25**, p. 321) has shown that, in the Erzgebirge, lead and zinc are, in common with tin, connected with the consolidation of the granite. The tin has been deposited in or near the granite and the lead and zinc at a greater distance, although no sharp boundary can be drawn between them. Small quantities of tungsten, bismuth, molybdenum, cobalt and silver are also mined in connection with the Erzgebirge tin ores. Associations of tin and silver are not so common as those of tin and copper, but in the Bolivian deposits silver forms an important part of the ore. It occurs so intimately intermingled and intergrown with the tin ore that at times the two cannot be separated by hand sorting (**9**, p. 217). Bismuth, and to a smaller extent, lead and zinc, are produced from these deposits. An unusual occurrence of tin is that of Campiglia Marittima, Tuscany (**12**, p. 135), where cassiterite occurs with limonite as a replacement deposit in limestone. The more common mineral associations of tin deposits such as fluorite, topaz, tourmaline, etc., are lacking in this deposit.

GENESIS.

Differentiation.

To understand the after actions in the granite magmas which result in the formation of tin deposits, a short outline of the assumed mode of formation of the acid differentiates of the granite is necessary. The undifferentiated granite magma may be considered as a solution containing, besides the granitic portion, a certain amount of water vapor and "mineralizers" or vapors of chemically active elements, such as Fl, Bo and Cl. As the magma cools the relative solubility of the different parts will decrease and it will split up into two parts, one of which will have approximately the composition of the final crystallized granite, while the other contains the excess of silica, a portion of the alkalies, and practically all of the water and mineralizers: the "acid extract." As water cannot remain liquid above 365° C., it is probable that this aqueous acid extract will be in a gaseous state. If the magma remains viscous any considerable time, and the cover be such as to prevent the escape of these gases, they may react on the granite, giving original topaz, tourmaline and cassiterite, or forming border zones or ill-defined schlieren of pegmatite and the tourmaline knots described from many tin granites. When the granite and heated wall rocks shrink on cooling, cracks will form which will be filled with the acid extract, resulting in dikes of quartz porphyry, pegmatite (and aplite) or quartz veins, according to the degree to which differentiation has progressed. The first separation of the original solution may give a felsitic rock not greatly different from the granite and one of the last products is the quartz vein. Tin seems to be confined to the latter part of this successive splitting up into immiscible solutions. Cassiterite, in notable amounts, appears in the pegmatite stage and continues to the quartz veins. The final liquid or gaseous products may react on the already formed pegmatites or porphyries in much the same way that the earlier differentiates react on the granite.

No sharp lines of division can be drawn between the various

acid differentiates. In many of the more important lode deposit regions the acid extract appears to have divided into a rock of the quartz-porphyry type, not greatly different from the granite, and into an extreme acid phase, or quartz veins. In such cases pegmatite where present in association with the ore deposits is rarely tin-bearing. In the less important lode deposit regions, tin-bearing pegmatites may be a prominent feature. Here the differentiate appears to be confined mostly to one phase and although quartz veins and quartz porphyry dikes may also be found the pegmatite contains the greater portion of the acid extract. The result is that, whereas in the first case, the vapors containing the tin were largely concentrated in the quartz vein phase of the differentiation, in this case they are mixed with the granitic material of the pegmatite.

Greisen.

Mineralogical Character.—Greisenization may be considered as one of the last phases of the work of the acid extract. Greisen, an alteration product of granite, consists essentially of quartz and mica with varying amounts of fluorine and boron minerals, such as topaz and tourmaline and is always present to a greater or less extent in close association with tin deposits. It may be found either as a rock mass of considerable size or as a local alteration product of the wall rock. Where a network of small fissures affords a favorable situation, the entire rock mass may be converted into greisen; where the fissures are more widely spaced, greisen bands follow the walls of the veins. Where the veins cut the invaded rock, a metasomatic alteration product, essentially similar to greisen, is formed. Greisen does not necessarily imply the presence of cassiterite, but where this mineral is present in the fissures it is generally found in the greisen as well. It usually replaces the feldspar, though a case is cited from the Transvaal (**56**, p. 101) where the quartz is partly replaced while the feldspar is unaltered. Although carbonates are mentioned in several of the microscopic descriptions of greisen, carbonic acid does not seem to have played a conspicuous part in this stage of

rock alteration, but the kaolinization of the feldspars in the upper parts of tin lodes appears to be the result of the action of the carbon dioxide of the acid extract.

In Cornwall tourmalinization is dominant. The common type in the Camborne area (**46**, p. 57) is the replacement of feldspar by quartz and blue tourmaline, while the original tourmaline in the normal granite is usually brown; and the biotite is altered to chlorite. In the greisenized granite of Cligga Head (**79**, p. 149) the minerals resulting from the metasomatic action are secondary quartz, muscovite, topaz, brown tourmaline, and a small amount of cassiterite. Of these it is considered that the quartz, muscovite and topaz replace the feldspar, while the brown tourmaline is an alteration product of the biotite.

In Tasmania (**35**, p. 433) tourmalinization is important. In the alteration of the schist and slate tourmaline is the principal mineral formed, although siderite and topaz are present in small amounts; but in the alteration of the quartz porphyry, or true greisenization, topaz is the most important secondary mineral. Cassiterite, pyrite, arsenopyrite and fluorite also occur, as replacements of the feldspars and groundmass. In South Africa the granite near the walls of the veins and in the peculiar pipe deposits has been altered to a rock consisting of tourmaline, quartz and cassiterite. Fluorite is common, and sericite is a characteristic mineral in some places. Wolframite, molybdenite, allanite, arsenopyrite, iron-lime carbonate, chlorite and topaz often occur. A South African greisen of the topaz bearing variety is described by Beck (**8**, p. 206), in which quartz is the principal mineral, followed in amount by lithia-free light yellow mica, with topaz third in importance.

In the Erzgebirge greisen, topaz is prominent, and tourmaline absent. A typical greisen (**25**, p. 319) from this region consists of the following minerals:

Quartz	50.28
Topaz	12.14
White mica (lithia bearing)	36.80
Cassiterite	0.43
	99.61

In places, however, the rock may contain as much as 90 per cent. of topaz.

Greisen is rare in the island of Banka (**89**, p. 135) but a specimen studied by Beck (**6**) consists of quartz and white lithia mica, together with topaz, cassiterite and wolframite. The topaz forms between 20 and 25 per cent. of the rock, by weight.

In the greisen of New South Wales (**21**, p. 223) neither topazization nor tourmalinization has taken place. The quartz is in part replaced by white mica, probably fluorine bearing, and the feldspar by secondary quartz and white mica. The biotite has in part resisted replacement and is in part altered to white mica. Fluorite is present in small amount near the vein, but topaz is only found in the vein itself. The immediate wall of the vein contains the greatest amount of quartz.

A greisen connected with non-stanniferous granite has been described from Grainsgill, Carrock Fell, England (**42**, p. 140). The original granite consists of oligoclase, orthoclase, quartz and biotite. In the greisen, biotite has disappeared, and the rock consists essentially of quartz and white, or slightly yellowish mica, with a little orthoclase. From the analysis (p. 244) it is evident that the soda and iron of the greisen are contained in the mica. No topaz, tourmaline or fluorite are present.

Chemical Changes Involved in Greisenization.—Although the pneumatolytic modifications of the granite, included under the term greisen, show wide mineralogic variety, a comparison of the available analyses of granite and greisen shows certain constant features. Vogt (**91**, p. 146) states that greisenization involves the addition of SiO_2, B_2O_5, Fl (or HFl) and SnO_2 and

Ia. Granite (*10*, p. 32).

Ib. Greisen, quartz mica and topaz (*10*, p. 32).

Ic. Greisen, quartz and topaz (*10*, p. 32).

II. Constituents in grams in 100 c.c. of (*a*) granite, (*b*) first greisen, (*c*) second greisen.

III. Gain or loss in grams of each constituent in alteration to (*b*) first greisen, (*c*) second greisen.

IV. Gain or loss in percentage of total original rock mass, (*b*) first greisen, (*c*) second greisen.

V. Comparison of constituents contained in equal volumes of altered and fresh rocks: 100 = no change.

TABLE V.

ERZGEBIRGE GRANITE AND GREISEN.

	Ia.	Ib.	Ic.	IIa.	IIb.	IIc.	IIIb.	IIIc.	IVb.	IVc.	Vb.	Vc.
SiO_2	74.68	70.41	79.73	200.81	205.95	235.79	+ 5.14	+34.98	+1.92	+13.07	102.6	117.4
Al_2O_3	12.73	13.06[1]	10.24[1]	34.23	38.20[5]	30.51[7]	+ 3.97[8]	− 3.72[10]	+1.48[11]	− 1.39[12]		
Fe_2O_3	——	1.42	——	——	4.15	——	+ 4.15	——	+1.55	——		
FeO	3.00	5.09	——	8.07	14.89	——	+ 6.82	− 8.07	+2.55	− 3.02	169.7	
MgO	0.35	0.09	——	0.91	0.26	——	− 0.65	− 0.91	−0.24	− 0.34	28.0	
CaO	0.09	——[2]	——	0.24	——[6]	——	− 0.24[9]	− 0.24	−0.09[12]	− 0.09		
Na_2O+Li_2O	1.54	0.98	——	4.14	2.87	——	− 1.27	− 4.14	−0.47	− 1.55	69.2	
K_2O	4.64	3.01	——	12.48	8.80	——	− 3.68	−12.48	−1.38	− 4.66	70.5	
H_2O	1.17	(0.76)[3]	(1.92)[3]	3.15	2.20	5.72	− 0.93	+ 1.57	−0.35	+ 0.59	70.5	186.1
TiO_2	0.71	0.49	——	1.91	1.43	——	− 0.48	− 1.91	−0.18	− 0.71	75.1	
SnO_2	0.09	0.49	1.43	0.24	1.43	4.26	+ 1.19	+ 4.02	+0.44	+ 1.51	592.2	932.2
AlF_3	——	3.91[4]	6.68[4]	——	11.41	19.55	+11.41	+19.55	+4.26	+ 7.30		
CaF_2	——	0.29	——	——	0.84	——	+ 0.84	——	+0.31	——		
CuO	0.50	——	——	1.34	——	——	− 1.34	− 1.34	−0.50	− 0.50		
Total	99.50	100.00	100.00	267.62	292.45	295.82	+24.93	+27.31	+9.30	+10.21		
Al	6.73	7.86	7.57	18.10	22.96	22.55	+ 4.86	+ 4.45	+1.82	+ 1.66	126.9	124.9
Fl	not deter.	3.10	4.53	——	9.07	10.72	+ 9.07	+10.72	+3.39	+ 4.01		
Sp. Gr.	2.689	2.925	2.961									

[1] After deduction of part of Al.
[2] CaO calculated as CaF_2.
[3] By difference.
[4] Calculated value.
[5] Al_2O_3 as given in original analysis (14.86 per cent.) would give 43.47.
[6] CaO as given in original analysis (0.21) would give 0.63.
[7] Al_2O_3 as given in original analysis (14.31 per cent.) would give 42.37.
[8] + 9.24 if all Al calculated as Al_2O_3.
[9] + 0.39 if Ca calculated as CaO.
[10] + 8.14 if all Al calculated as Al_2O_3.
[11] + 3.44 if all Al calculated as Al_2O_3.
[12] + 0.14 if Ca calculated as CaO.
[13] + 3.03 if all Al calculated as Al_2O_3.

often also of Li_2O, K_2O and perhaps Al_2O_3, and the abstraction of CaO, MgO, and Na_2O, and often also of K_2O and Al_2O_3. For the Erzgebirge greisen, Dalmer (**25**, p. 319) considers that the principal changes involve the addition of FeO, Fl, SnO_2 and possibly Al_2O_3 and loss of K_2O, Na_2O and SiO_2 and Lindgren (**57**, p. 622) remarks that the formation of greisen does not by any means involve silicification. Cotton (**21**, p. 231) considers that the constituents of the greisenizing solution were chiefly SiO_2, FeO, MgO, SnO_2, MoS_2 and Al_2O_3.

In order to determine the actual gains and losses from a comparison of analyses, it is necessary to know the composition of equal volumes of granite and greisen from each locality. As any possible porosity in either the granite or greisen is probably small enough to be negligible, the weight of a given volume may be determined from its specific gravity. Unfortunately, however, except in the case of the Grainsgill rocks, no specific gravity determinations were given with the analyses. Hence it is necessary to obtain a value for the specific gravity by calculating the mineral composition from the analyses and multiplying the percentage weight of each mineral by its specific gravity. The composition of a hundred cubic centimeters of the rock is then obtained by multiplying each component of the chemical analysis by the calculated specific gravity.

For the Erzgebirge two analyses of greisen are available for comparison with the granite. The assumed mineral composition of the granite is as follows:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	44.32	2.66	117.80
Orthoclase	23.73	2.55	60.51
Plagioclase (Ab_1An_1)	13.59	2.615	35.54
Mica	13.33	2.9	38.66
Ilmenite	0.97	3.5	3.40
Tourmaline and topaz	4.06	3.2	12.99
	100.00		268.90

Calculated specific gravity, 2.689.

Of the two types of greisen considered, one (column I*b* of Table V.) is the normal type and is composed of quartz, lithia-bearing mica and topaz. The analysis, recalculated in terms of mineral composition, gives:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	55.72	2.66	148.17
Mica	26.35	2.9	76.42
Topaz	14.38	3.5	50.32
Hematite	1.50	5.2	7.80
Ilmenite	0.95	4.75	4.51
Fluorite	0.64	3.182	2.03
Cassiterite	0.47	7.0	3.29
	100.01		292.54

Calculated specific gravity, 2.925.

The second greisen is a more extreme type and consists principally of quartz and topaz. The following mineral composition is obtained from the analysis:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	69.57	2.655	184.70
Topaz	29.03	3.5	101.50
Cassiterite	1.41	7.0	9.87
	100.01		296.07

Calculated specific gravity, 2.961.

In Table V. are given the three analyses and the calculated compositions of 100 cubic centimeters of each rock (columns II*a*, II*b* and II*c*) obtained by multiplying the percentage weight of each constituent in the analysis by the specific gravity. Column III*b* and III*c* represent the actual gains and losses, in grams, in the alteration of 100 cubic centimeters of granite to greisen, in other words, II*b*–II*a* and II*c*–II*a*. The same gains and losses, but expressed as percentages of the total rock mass are given in columns IV*b* and IV*c*, the figures being obtained by dividing the figure for actual gain or loss of each constituent by the weight of 100 cubic centimeters of the unaltered granite

(265.13). Columns V*b* and V*c* are ratios of the weights of each constituent in 100 cubic centimeters of the greisen to the corresponding weight in the granite, multiplied by 100, or for any constituent,

$$\frac{\text{II}b(\text{or II}c)}{\text{II}a} \times 100.$$

The fluorine as given in the original analyses is here combined with the calcium and a part of the aluminum as CaF_2 and AlF_3, and a proportionate amount of oxygen omitted. No water is given in the greisen analyses, and it is assumed that the low summation resulting from the recalculation of Al and Ca fluorides implies its presence. Columns III. and IV. of the table, in which the gain

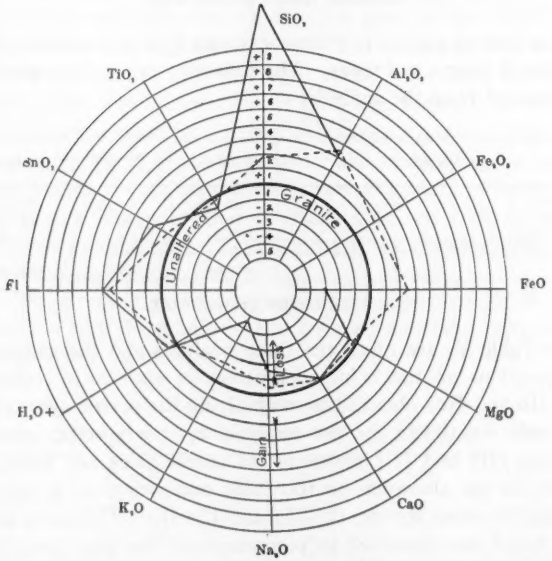

FIG. 29. Erzgebirge granite and greisen. Diagram illustrating gains and losses of chemical constituents, in terms of percentage of original granite, in alteration to greisen. Dotted lines represent mica-bearing greisen, full lines represent quartz topaz rock.

TABLE VI.

NEW SOUTH WALES GRANITE AND GREISEN.

	Ia.	Ib.	Ic.	IIa.	IIb.	IIc.	IIIb.	IIIc.	IVb.	IVc.	Vb.	Vc.
SiO_2	76.69	75.42	78.47	204.23	212.68	221.29	+ 8.45	+17.06	+3.19	+6.44	104.0	108.0
Al_2O_3	10.89	12.98	11.50	29.00	36.60	32.43	+ 7.60	+ 3.43	+2.87	+1.29	126.2	111.4
Fe_2O_3	0.76	1.66	2.64	2.02	4.68	7.44	+ 2.66	+ 5.42	+1.01	+2.04	231.7	368.4
FeO	0.39	0.58	1.05	1.04	1.64	2.96	+ 0.60	+ 1.92	+0.23	+0.72	226.4	284.6
MgO	0.18	0.23	0.49	0.48	0.65	1.38	+ 0.17	+ 0.90	+0.06	+0.34	135.4	287.5
CaO	1.73	0.10	——	4.61	0.28	——	− 4.33	− 4.61	−1.64	−1.74	6.1	
Na_2O	5.35	3.05	1.99	14.25	8.60	5.61	− 5.65	− 8.64	−2.16	−3.26	60.4	39.4
K_2O	2.97	1.62	1.17	7.91	4.57	3.30	− 3.34	− 4.61	−1.27	−1.74	59.1	41.7
H_2O+	0.13	0.47	0.23	0.35	1.33	0.65	+ 0.98	+ 0.30	+0.37	+0.11	380.0	185.7
H_2O-	0.37	1.31	1.17	1.24	3.70	3.30	+ 2.46	+ 2.06	+0.93	+0.78		
TiO_2	——	0.15	0.22		0.42	0.62	+ 0.42	+ 0.62	+0.16	+0.24		
SnO_2	——	0.22	0.08	——	0.62	0.23	+ 0.62	+ 0.23	+0.24	+0.09		
MoS_2[1]	——	1.69	0.80	——	4.77	2.26	+ 4.77	+ 2.26	+1.81	+0.85		
F[2]	n.d.	n.d.	n.d.									
Total	99.46	99.48	99.81	265.13	280.54	281.47	+15.41	+16.34	+5.80	+5.79		
Sp. Gr.	2.663	2.825	2.824									

[1] Calculated from S. [2] Present in all analysis but not determined.

Ia. Unaltered granite. Ib. Greisen away from vein. Ic. Greisen near vein wall.

II. Constituents in grams of 100 c.c. of (*a*) granite, (*b*) first greisen, (*c*) second greisen.

III. Gain or loss in grams of each constituent in alteration to (*b*) first greisen, (*c*) second greisen.

IV. Gain or loss in percentage of total original rock mass, (*b*) first greisen, (*c*) second greisen.

V. Comparison of constituents contained in equal volumes of altered and fresh rocks; 100 = no change.

and loss in grams and in percentages of the original rock mass are shown, show a loss in Al_2O_3, and CaO, but a compensating gain in AlF_3 and CaF_2, showing that a part of the oxygen is replaced by fluorine. As shown in the last line of the table, aluminum shows an absolute gain throughout the process of greisenization. The circular diagram (Fig. 29) used to illustrate the gains and losses in the alteration of granite to greisen, has been adopted from Ransome (**71a**, p, 181 and **71b**, p. 98). The gains and losses in the different constituents, in terms of percentages of the original rock mass (columns IV*b* and IV*c*) are plotted along radial lines. In this diagram, for the purpose of easier comparison, all the aluminum has been considered as Al_2O_3.

In a discussion of the metasomatic processes involved in the formation of greisen in New South Wales, Cotton (**21**) gives a series of analyses of granite and greisen which are particularly valuable for purposes of comparison, as the samples were taken at short intervals from the fissure vein, and each analysis is accompanied by a petrographic description of the sample taken. Unfortunately no specific gravities are given, hence it is necessary to recalculate the mineral composition as in the Erzgebirge analyses.

That of the granite (Column I*a*) is as follows:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	31.00	2.66	82.46
Orthoclase	14.77	2.55	37.66
Plagioclase (Ab_{10}, An_1)	48.46	2.645	128.17
Biotite	5.45	3.0	16.35
Hematite	0.31	5.2	1.64
	99.99		266.28

Calculated specific gravity, 2.663.

The sample of the intermediate greisen (I*b*) was taken at a distance of four inches from a small quartz vein and shows a partial alteration of the feldspars and biotite to white mica. The calculated mineral composition gives:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	61.30	2.655	162.75
Plagioclase	3.26	2.645	8.62
Biotite	5.24	3.0	15.72
White Mica	26.60	2.9	77.15
Molybdenite	1.80	4.75	8.69
Hematite	1.64	5.2	8.53
Cassiterite	0.15	7.0	1.05
	99.99		282.51

Calculated specific gravity, 2.825.

The third sample is of the completely greisenized rock 2 inches from the vein. Of the original constituents of the granite only a small amount of biotite remains. In the petrographic

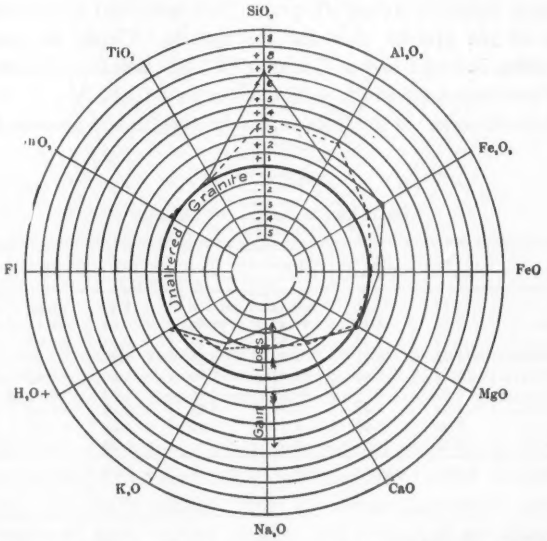

FIG. 30. New South Wales granite and greisen. Diagram illustrating gains and losses of chemical constituents, in terms of percentage of original rock, in the alteration of granite to greisen. Dotted lines represent partially altered rock, full lines completely altered rock. Areas have no significance.

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	67.57	2.652	179.19
White mica	21.64	2.9	62.94
Biotite	7.08	3.0	21.24
Molybdenite	0.81	4.75	3.85
Hematite	2.75	5.2	14.30
Cassiterite	0.15	7.0	1.05
	100.02		282.37

Calculated specific gravity, 2.824.

description the presence of a small amount of fluorite is noted, but as no fluorine is given in the analysis it was not included in the calculated mineral composition. As the secondary quartz, resulting from the alteration, contains numerous small cavities, a lower value for its specific gravity has been used in the calculation of the greisen than for the granite. Using the specific gravities obtained above, Columns II., III. and IV. of table IV has been calculated in the same manner as in Table V.

A third series of analyses represent granite and greisen from

TABLE VII.

GRAINSGILL GRANITE AND GREISEN.

	Ia. Granite.	Ib. Greisen.	IIa.	IIb.	III.	IV.	V.
SiO_2	75.22	80.36	197.35	215.68	+18.33	+6.99	109.3
Al_2O_3	11.14	11.12	29.23	29.85	+ 0.62	+0.24	100.8
FeO	1.77	1.77	4.64	4.75	+ 0.11	+0.04	102.4
MgO	1.08	0.57	2.83	1.53	− 1.30	−0.50	54.1
CaO	1.62	0.67	4.25	1.80	− 2.45	−0.93	42.4
Na_2O	4.00	1.82	10.50	4.88	− 5.62	−2.14	46.5
K_2O	4.52	2.47	11.86	6.63	− 5.23	−1.99	55.9
H_2O	0.50	1.96	1.31	5.26	+ 3.95	+1.51	40.1
P_2O_5	0.15	——	0.39	——	− 0.39	−0.15	
Total	100.00	100.74	262.36	270.38	+ 8.02	+3.07	
Sp. gr.	2.624	2.684					

Ia. Granite. Ib. Greisen.

II. Constituents in grams in 100 c.c. of (*a*) granite, (*b*) greisen.
III. Gain or loss in grams in alteration to greisen.
IV. Gain or loss in percentage of total original rock mass.

a non-stanniferous area, Grainsgill, England, described by Harker (42). Here the specific gravities are given, so that the composition of equal volumes of the two rocks is obtained without the necessity of recalculating the analyses. The alteration products described in the greisen are secondary quartz and light-colored mica.

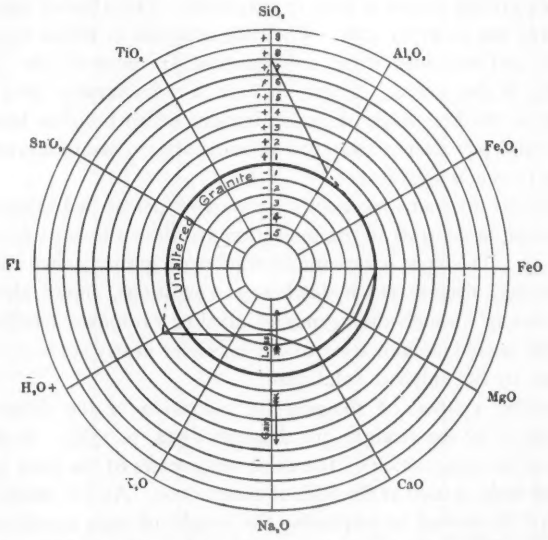

FIG. 31. Grainsgill granite and greisen. Diagram illustrating gains and losses of chemical constituents, in terms of percentage of original granite, in alteration to greisen. Unconnected lines indicate absence of constituents.

The three examples of greisen considered above show marked mineralogical differences, but the comparison of equal volumes of granite with each greisen, gives a very similar result for the alteration of each. Gains in silica and aluminum are shown in all cases, the silicification increasing with the greater completeness of alteration. In the Erzgebirge it is aluminum rather than alumina which shows the greatest gain in volume. The iron

oxides show gains, though in the extreme alteration represented by the second Erzgebirge greisen, FeO and Fe_2O_3 are lacking. Lime and magnesia are present in too small amounts to warrant any definite statements as to their changes, as small errors in the analyses or calculations would alter the results. However, both appear to have lost in amount, though the second New South Wales greisen shows a gain in magnesia. The alkalies appear to have lost in every case. The only analyses in which hydroscopic and combined water are separated are those of the New South Wales rocks. There is here a considerable gain in water in the first stage of greisenization, which becomes less in the completely altered rock; the amounts are too small, however, to be of much significance.

Circular diagrams representing the two types of hydrothermal alteration in contrast to greisenization are shown in Fig. 32 and Fig. 33. The first, a sericitic alteration of granodiorite, under moderately deep-seated hydrothermal conditions, shows alteration mainly through the agency of alkaline carbonate solutions, and the second, an alteration of dacite, under nearly surface conditions, by hot sulphate solutions.

Another method of showing the alteration of the different granites is by the straight line diagram (**58a**, p. 138). In this method the composition of 100 cubic centimeters of the fresh and altered rocks is used as the basis of comparison. As it is the gains which it is desired to emphasize the weight of each constituent of the greisen is divided by the weight of the same constituent in the granite, and the quotient, multiplied by 100, is plotted for each pair of analyses compared. For convenience a logarithmic scale is used, as otherwise the lines would be too long. Different lines connect the constituents of each analysis. For the purpose of comparison with other types of rock alteration, two other types, one a granodiorite from Willow Creek, Idaho (**57**, p. 669) and the other a dacite from Goldfield (**71a**, p. 151) have been shown in red.

In this diagram the parallelism of the lines connecting the

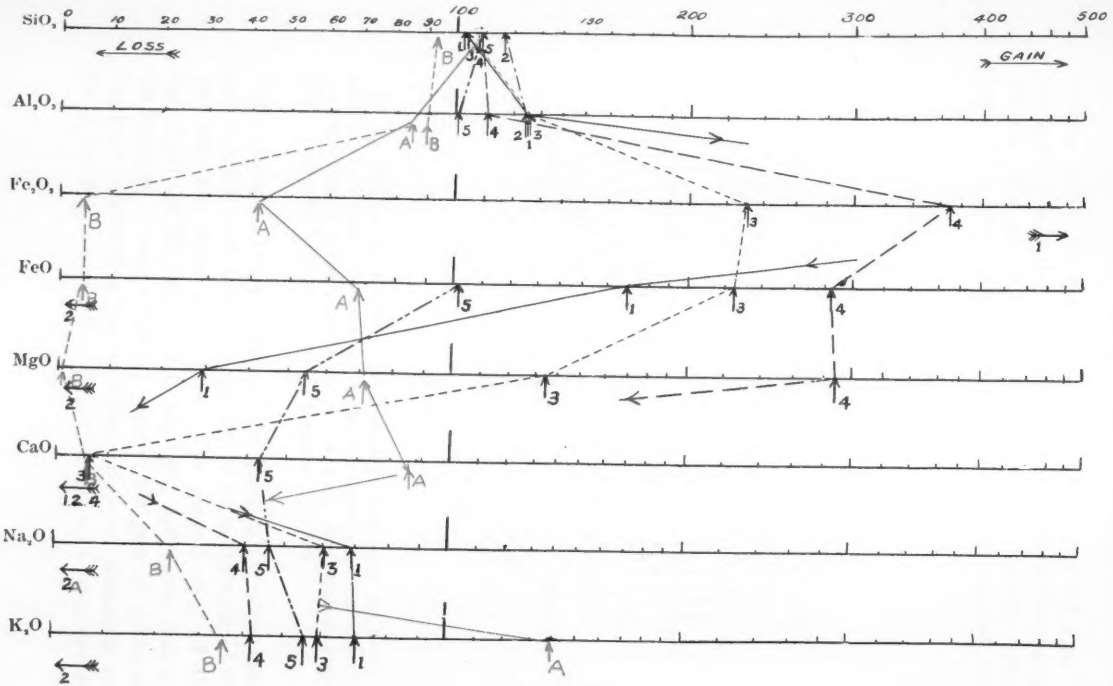

PLATE I.

Logarithmic straight line diagram showing alteration in different constituents of granite in change to greisen. To right of 100 point shows gain, to left loss. Horizontal arrow on left indicates complete loss, on right, new accession. (1) Erzgebirge greisen; (2) Erzgebirge quartz-topaz greisen; (3) New South Wales intermediate rock; (4) New South Wales greisen; (5) Grainsgill greisen. *A*, Willow Creek, Idaho, altered granodiorite; *B*, Goldfield, Nevada, altered dacite.

different points for the individual constituents of the granites and greisens, is fairly close, indicating somewhat similar changes for all. The points for silica are all close together, implying a fairly even accession in proportion to the amount orig-

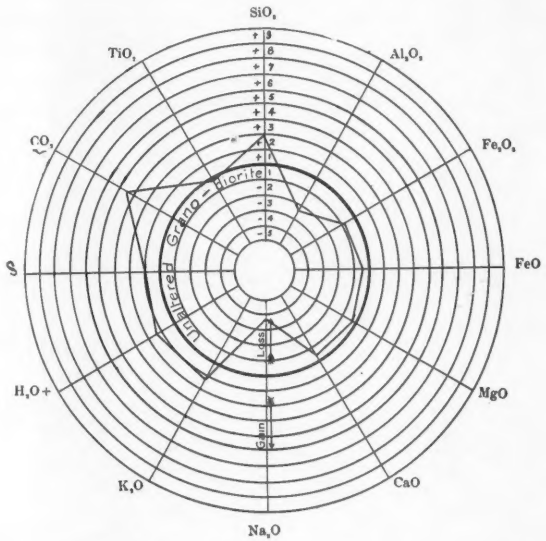

FIG. 32. Willow Creek, Idaho. Diagram illustrating gains and losses of chemical constituents, in terms of percentage of original granite, in alteration to greisen. Radial distances correspond to 1 per cent. Areas have no significance. (Compiled from analysis of W. Lindgren 57, p. 669.)

inally present. The positions of the alumina (or aluminum) points extend over a wider range but all lie to the right of the 100 line, and hence show gain. The general slant of the lines from the SiO_2 points is to the right, and shows that for the amounts of each originally present, the gain of aluminum has been greater than that of silica. Between aluminum and Fe_2O_3 the lines slant to the right, which shows a great propor-

tionate gain in Fe_2O_3. In contrast to this are the two hydrothermal alterations shown in red, where the slant to the left shows greater loss. Likewise the FeO shows a less gain for the greisen and, on the contrary, less loss in the hydrothermal alterations. The magnesia, and particularly the lime both show heavy losses, greater for the lime than the magnesia, in contrast to the hydrothermal alterations where the lines slant in the

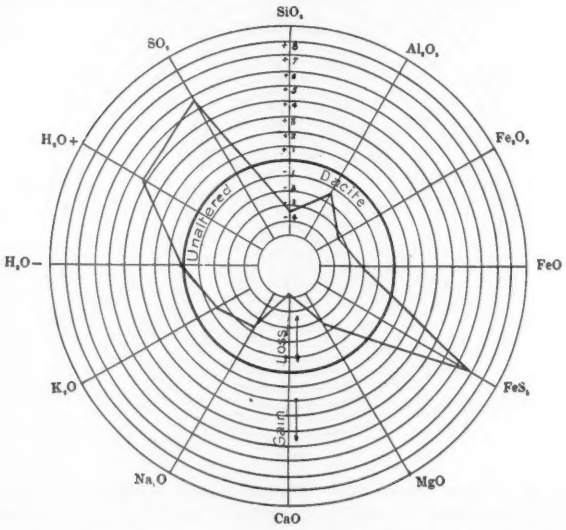

FIG. 33. Goldfield, Nevada, dacite. Diagram illustrating gains and losses of chemical constituents, in terms of percentage of original rock, in the alteration of fresh dacite. Radial distances correspond to 1 per cent. Areas have no significance. (Ransome *71a*, p. 151.)

opposite direction. The alkalies show less proportional loss than the lime and magnesia. It is interesting to note that, in the attack on the alkalies, very slight selective action is shown by the nearly vertical lines connecting the points for potash and soda. It appears that under the conditions of greisenization, the soda is

not dissolved in a much greater proportion than the potash. This is again in marked contrast to the hydrothermal alterations, where in the Goldfield case, the soda appears to be distinctly more soluble, and in the Willow Creek type, where there is a loss in soda, but an actual gain in potash.

The method of calculation employed in the foregoing tables involves a certain amount of error: first, in the possible difference in porosity between the granite and greisen; second, in assigning the proportions of different minerals where the petrographic description gives no good quantitative statement as to the amounts present; third, in the assignment of values for specific gravities to such minerals as micas, where the specific gravity varies over a wide range; and, fourth, in the fact that the totals of the analyses vary from 100. That errors, arising from a possible difference in porosity between the granite and greisen are not sufficiently large to vitiate the results obtained, is shown by the calculation of the excess porosity of the greisen over the granite which would be necessary to balance the gains shown in the tables. The three smallest gains in any important constituent are those of silica in greisen "b" of the Erzgebirge and New South Wales and of alumina in the Grainsgill greisen. If the silica in the first had remained constant, the porosity of the greisen would have to exceed that of the granite by 2.5 per cent. In the same way, excess porosities of 2.3 and 3.8 per cent. are necessary to equalize the gains in alumina and silica in the Grainsgill and New South Wales greisen respectively. For aluminum to have remained constant in the first Erzgebirge greisen, an excess porosity of 22.5 per cent. is necessary. It is evident that errors of the second and third classes tend to be the same in both granite and greisen, and hence more or less counterbalance each other. In order to determine how far these errors might affect the results, specific gravities were calculated for the Grainsgill granite and greisen.

The calculated specific gravity of the granite is to the determined, as 1.018 is to 1, and of the greisen, as 1.022 is to 1, hence it is probable that no appreciable error is introduced by using

Granite:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	36.91	2.66	98.18
Orthoclase	22.32	2.55	56.91
Plagioclase (Ab_3An_1)	29.86	2.649	79.10
Biotite	9.89	3.0	29.67
Apatite	1.01	3.2	3.24
	99.99		267.10

Calculated specific gravity, 2.671.
Determined specific gravity, 2.624.
Difference 0.047.

Greisen:

Mineral.	Per Cent.	Assumed Specific Gravity.	Weight.
Quartz	58.87	2.66	156.60
Orthoclase	4.41	2.55	11.27
Muscovite	36.71	2.9	106.45
	99.99		274.32

Calculated specific gravity, 2.743.
Determined specific gravity, 2.684.
Difference 0.059.

calculated specific gravities in the other two comparisons. For most of the changes shown in the tables, a considerable error in calculation would be necessary in order to affect the result. For instance, in the New South Wales greisen, if alumina had remained constant, it would imply an error in the specific gravity of 2.825 — 29.00/12.98, or .591 for the first greisen, and 2.824 — 29.00/11.50, or .303 for the second. It is clearly impossible that such large errors could have been introduced. The error arising from the fact that the sums of the analyses vary slightly from 100, is certainly too small to be of any significance, and is probably less than errors in the analyses themselves.

To sum up the chemical alterations involved in greisenization, the writers believe that they have been able to show, by means of the volume calculations used in the preceding pages that there is an increase in silica, aluminum (which is only in part Al_2O_3) and probably of the iron oxides, a loss of lime, magnesia and the alkalies, the losses of the alkalies being approximately in propor-

tion to the amount of each originally present and only in slight degree selective. This conclusion is in accord with that of Vogt except as to the possible addition of K_2O and abstraction of Al_2O_3, with Dalmer except as to the possible loss of SiO_2 and with Cotton except as to the gain in magnesia.

Formation of Tin Deposits.

The close connection which has been shown to exist between tin deposits and granitic intrusives points to the granite magma as the ultimate source of tin. Its extraction and collection from the magma itself is attributed to the action of mineralizers. This process of formation of minerals by the reaction of gases and vapors upon one another is termed pneumatolysis.

Vogt (**91**, p. 475) believes that the action of hydrofluoric and hydrochloric acids on a cooling magma under dominant gaseous conditions, effects an extraction of tin, boron and other elements. Daubrée (**30**, p. 23) has shown that cassiterite may be produced synthetically by the mutual reactions of stannic chloride and water. Cassiterite has been produced by the analogous reaction of stannic fluoride and water, with the liberation of hydrofluoric acid, thus:

$$SnF_4 + 2H_2O = SnO_2 + 4HF.$$

It is probable that this reaction goes on in nature and that the hydrofluoric acid liberated is taken up in the formation of fluorine-bearing minerals such as fluorite and topaz. The presence of fluorine in nearly every tin deposit has already been emphasized (Fig. 28).

From studies of individual deposits some writers have suggested that boron plays an essential part in the formation of cassiterite, but the more general association of fluorine in tin deposits shows that while fluorine is apparently an essential factor, boron accompanies rather than aids in the formation of cassiterite.

The mineralizers derived from the cooling magma will react on the upper portions of the granite, to form greisen, and there

deposit their tin content. The action of ascending vapors is largely confined to the replacement of already formed minerals, a phase of metasomatic replacement for which Krusch (**55a**, p. 165) has used the term pneumatolytic-metasomatism.

Although pneumatolytic-metasomatism plays the most important rôle in the formation of tin deposits, other processes are also effective and there appears to be a gradation between different modes of origin, although emanations from the granitic magma are always a controlling factor. Cassiterite is found as an original constituent in granite and pegmatite. It is formed by pneumatolysis, pneumatolytic-metasomatism, and in a few cases by contact metamorphism, although with tin deposits sharp lines of division between them cannot always be drawn. The gradation extends still farther to include deposits formed by hydrothermal processes, and as an end phase the deposition of cassiterite from thermal springs under atmospheric pressure.

Cassiterite is considered by Beck (**6**, p. 121) to be an original constituent of the granite of Banca and Billiton. It is also said to be a microscopic constituent of the Eibenstock granite (**9**, p. 209), of which the silicates also contain tin, namely: lithia-iron mica, 0.32 per cent.; orthoclase, 0.019 per cent.; plagioclase, 0.074 per cent. SnO_2. Von Micklucho-Maclay (**60**, p. 88) reports cassiterite as an inclusion in the mica of a granite accompanied by rutile, topaz, apatite and tourmaline. Cassiterite is also an important original constituent in pegmatites of the Carolinas and the Black Hills.

The majority of the tin deposits described in this paper appear to owe their origin to pneumatolytic-metasomatic and pneumatolytic processes. As an example may be mentioned the alteration of the Altenberg granite to zwitter, a metasomatic replacement of feldspar by pneumatolytic minerals containing fluorine, boron, lithium and other mineralizing agents.

Contact metamorphism, in the narrow sense of the term, is not important in the formation of tin deposits. True contact metamorphic cassiterite however occurs in a hornfels rock in Devonshire, England (**16**, p. 101). This rock is the result of the in-

tense contact metamorphism of a schist by intrusive granite, and consists essentially of light-colored mica and quartz but also contains tourmaline, apatite, zircon, chlorite and innumerable small grains of cassiterite of about 1–2 mm. in diameter. At Ear Mountain, Alaska (**52**, p. 29), microscopic grains of cassiterite are imbedded in some minerals of a tourmaline-axinite-hornfels rock, but this is stated to be the only case of contact metamorphic cassiterite in the entire Alaskan region. Some authors have ascribed such deposits as Schwarzenberg and Pitkäranta to this mode of origin but Dalmer (**28**, p. 272) considers that, although the silver-lead-zinc deposits of Schwarzenberg are of contact metamorphic origin, the tin deposits cannot be considered as such, but as "lager imprägnationen" due to pneumatolytic action. Similarly in the deposits of Pitkäranta, the iron and copper ores are contact deposits but the tin occurs as a lining in druses of a regionally metamorphosed lime-silicate rock and cannot be ascribed to this origin. Contact metamorphic deposits are genetically associated with the tin granite intrusions of the Zeehan Field, Tasmania. They contain magnetite, sulphides, garnet, actinolite, diopside, epidote, vesuvianite and other characteristic contact minerals but are barren of cassiterite although there are tin deposits of pneumatolytic origin in the immediate vicinity. It would thus appear that true contact metamorphic deposits containing tin are of rare occurrence.

Under tin deposits formed by hydrothermal processes may be included such types as those of the "Transmetamorphic Zone" in the Zeehan Field of Tasmania (**87**). The deposits of this zone are subdivided into the pyrite-stannite and siderite-stannite types and represent the farthest migration of the mineralizing solutions from the granite intrusive. The veins sometimes show crustified fillings and are characterized by the presence of siderite, stannite, galena, pyrite, chalcopyrite, sphalerite and some cassiterite. Other deposits which might be included in this class are the stannite veins of the New England District, New South Wales, and Alaska, and the cassiterite-limonite deposits of Campiglia Marittima. Cassiterite is found as kernels and microlites in zinc-

blende from Campiglia Marittima (**12**, p. 156) and from Hilbersdorf and Berthelsdorf in Freiberg (**12**, p. 135). The zinc-blende from the latter localities contains as much as 0.4 per cent. Sn.

An example of tin deposits formed under conditions of less depth and therefore less pressure than those previously considered, are the Mexican deposits in rhyolite. Minerals indicative of formation under atmospheric pressure, such as chalcedony and opal, are associated with the cassiterite. Even a pseudomorphic replacement of marcasite by cassiterite is reported (**98**). An example of deposition of tin under atmospheric pressure is shown by the presence of cassiterite in siliceous sinter in New South Wales (**22**, p. 746). Tin oxide is reported in analyses of the thermal waters from Rippoldsau and Kissingen (**70**, p. 48). On the other hand the analysis by Meunier, of siliceous sinter from a hot spring in Malacca, which shows 0.05 per cent. SnO_2, has been attacked by Bott (**80**, p. 5) who claims to have found no trace of tin from any of the hot springs of the tin-granite area of Malacca and Selangor. The presence of cassiterite in a deer's horn taken from a river bed in Cornwall has been much quoted as an example of pseudomorphic replacement by cassiterite under atmospheric conditions. Scrivenor (**80**, p. 5), however, proved that the cassiterite was only mechanically entangled in the cavities of the horn.

Where the ore-bearing solutions contain both tin and other metals, the tin content is generally deposited near the intrusive and the more soluble constituents, such as lead and zinc, may remain in solution until they reach a zone of lower temperature and pressure. Thus may arise the zonal distribution sometimes found where cassiterite and other ores are genetically dependent upon the same granitic intrusive. The approximate genetic distribution of some of the more common minerals associated with cassiterite is shown graphically in Fig. 34. It is not to be inferred from this diagram that the minerals are diagnostic of the different modes of origin under which they are placed, but roughly represent the genetic conditions under which they were formed in connection with cassiterite only. The relative importance of the different genetic types is not considered.

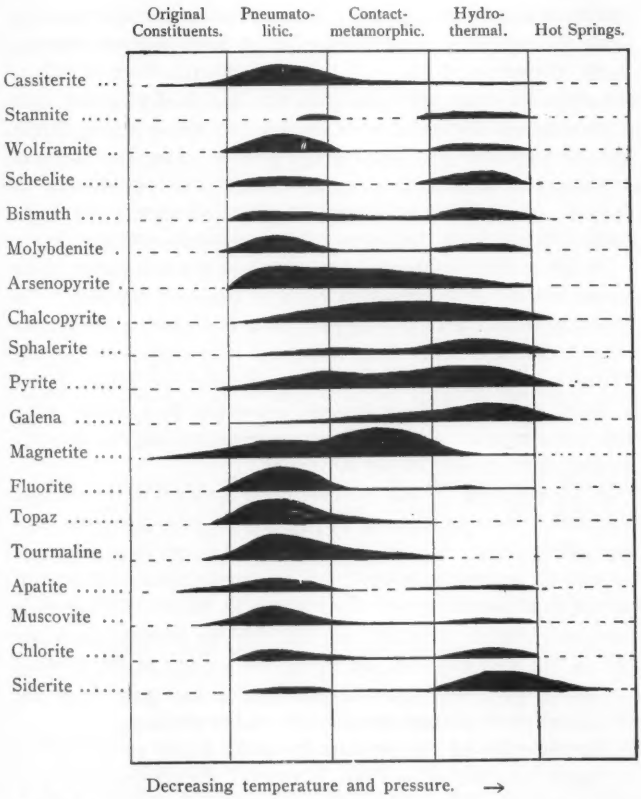

FIG. 34. Diagram to illustrate the genetic distribution and gradation of some of the more common minerals in their association with casserite only.

SUMMARY.

Previous writers have emphasized the general association of tin and granite, and the data collected in the foregoing paragraphs confirms this. As a rule the intrusion which forms the mother rock of the tin deposits is in batholithic form. Nothing

can be deduced from the age of the intrusives, except that they range throughout all geologic time but are perhaps most numerous in the Permian and Mesozoic times. Although there is little in the chemical composition of such granites to distinguish them from nonstanniferous varieties, except they are as a rule alkalic, and more potassic than the average granite. The rocks invaded by the granite do not exert any influence on the formation of tin deposits, nor is the contact metamorphism of these rocks essentially different from that effected by non-stanniferous granites.

Of the tin deposits themselves, lodes, and to a less extent stockworks, are the most important types of bed-rock deposits. The fissure systems often show, by position with respect to the granite contact, that they result from shrinkage following cooling of the intrusives. Original cassiterite in pegmatite sometimes forms workable lodes, but these are less important than fissure veins and lode-fissures. Pipes and segregations are interesting geologically but are only locally important.

In the majority of cases studied, tin is confined to the granite. nor does it ever migrate to any great distance from the contact. From this it follows that the extent to which erosion has cut into the granite batholith is an important factor in determining the localities where tin deposits may be found. In a granite mass only slightly denuded, deposits may be expected over any part of the area exposed, but where the erosion of tin granites has been greater, tin is generally confined to such portions of the margin as show average gentle dips of the contact.

The minerals of tin deposits generally show conditions of formation assumed to be characteristic of the pneumatolytic or deep vein zones. Fluorine bearing minerals are almost invariably present, and boron minerals common. Tungsten and copper ores and less commonly ores of bismuth, silver, lead and zinc are often associates of cassiterite.

Cassiterite is derived from the original granitic magma through the action of the "acid extract." The effect of tin-bearing solutions in gaseous or liquid forms has been shown by a comparison of granite and greisen analyses to consist of the addition of

fluorine, alumina, tin oxide, the iron oxides and probably silica, and the abstraction of the alkalies.

Cassiterite is capable of formation under a variety of conditions. It may be found (1) as an original constituent of granite and pegmatite, (2) as a result of pneumatolysis and pneumatolytic-metasomatism, (3) as a true contact metamorphic mineral, or (4) it may be deposited under hydrothermal conditions, or even (5) at atmospheric pressure in the deposits of thermal springs. Of these modes of formation only the second and to a lesser extent the first are of much commercial significance.

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SOME GENETIC RELATIONS OF TIN DEPOSITS.

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Since the days of Werner, the different kinds of veins have been divided into groups according to their most prominent and characteristic features. To these groups, Werner applied the term *vein formation;* other authors have subsequently also used the term *vein type.* Even in Werner's time, it was difficult to fit all known veins into sharply defined groups. With the rapid increase in our knowledge of ore deposits in recent years, as more and more new mining districts have been discovered and described, the dividing lines between these groups have become less and less sharp, and in many cases complete transition exists from one group to another.

Among these groups, *tin veins* have stood out more distinct than probably any other type. They are almost always closely associated with granitic rocks; and are characterized by an abundance of fluorine and boron, and to a less extent lithium and phosphorus minerals, and the pneumatolytic metamorphism of the country rock. To one familiar only with the more common vein types, a more different group could hardly be pictured. Yet, notwithstanding the unusual characteristics of this group of veins, there are many transitional types which closely relate it to other groups. These transitions have been brought about by minerals, which in the type are accessory constituents of the vein filling, becoming the most prominent; and by the entrance into the vein filling of new minerals, and the disappearance of some of the characteristic features of the type.

No less distinct than the type itself, has the genesis of this group been considered. Moreover, our understanding of the genesis of this group dates back further and is considered more certain than in the case of any other. As early as 1841,[1]

[1] Daubrée: *Annales des Mines,* 3d Ser., Vol. XX., 1841, pp. 65–112.

Daubrée called attention to the fact that all tin veins are associated with granitic rocks, and that the tin and other characteristic elements of these veins were derived directly from the granitic magma. His synthetic experiments enabled him to arrive at conclusions as to the chemical processes involved. As the magma cooled, metalliferous gases and vapors were given off; and these, reaching the already solidified peripheral portions and the adjoining country rock, deposited their metallic contents, and at the same time, reacting chemically on those rocks, produced the profound metamorphism so constantly associated with these veins. Daubrée's theory was substantiated by the observations of his contemporary Elie de Beaumont[1] and is today accepted as the explanation of the origin of this type of veins. So radically different was this theory from the views held as to the genesis of veins in general, that the older French school drew a sharp line between *tin veins* and *sulphide veins,* and some went so far as to divide all veins into two main groups—*Filons stannifères* and *Filons sulphurés dites plombifères;* the former fumerolic products of granitic magmas, the latter hydrothermal deposits. Such a genetic isolation of this group is no longer tenable.

In the following paragraphs, I shall discuss briefly some transitional occurrences of tin deposits and point out their genetic significance.

PEGMATITIC DEPOSITS.

There are no magmatic segregations of cassiterite of economic importance; yet cassiterite is frequently found as a primary constituent of granite in tin districts. In pegmatite dikes, however, there are occurrences of sufficient richness to make a workable ore.

Most closely related to a normal granite is the rock in which occurs the tin deposit at Etta Knob in the Black Hills of South Dakota. The acid intrusive there is in the form of a stock with a nearly circular outcrop, measuring from 30 to 60 m. in diameter. This rock is an unusually coarse grained pegmatite,

[1] Elie de Beaumont: *Bull. de la Soc. Géol. de France,* 2d Ser., Vol. IV., 1847, pp. 1249–1333.

carrying feldspar crystals up to 50 cm. long and spodumene crystals as large as 12 m. in length and 1 m. in thickness. The tin ore occurs disseminated in the form of small granules and imperfect crystals making up about 2½ per cent. of the rock. This rock is characterized by an abundance of lithium and phosphorus minerals, and the lack of the usual fluorine and boron minerals of the tin veins. Though recognizing the pegmatitic character of the rock, Beck[1] and Bergeat[2] consider the occurrence so closely related to normal magmatic segregations that they have placed it in that category in their text books. Beyschlag, Krusch, and Vogt,[3] on the other hand, have placed it among the tin veins, because they hold that the tin, tantalum, lithium, and phosphoric acid have been introduced pneumatolytically. This difference in classification shows the transitional character of the deposit.

Very similar to the Black Hills occurrence is that of North and South Carolina, but here the pegmatitic character of the rock is more pronounced; and, besides many of the minerals of the Black Hills deposit, fluorspar also occurs. This deposit represents then a stage nearer to true veins, and all of the above mentioned authors agree in placing it among the tin veins in their classification. Yet both of these occurrences differ from typical tin veins in the almost complete absence of a greisen formation.

Near Ober Graupen in Bohemia, at the southern end of the eastern belt of the Erzgebirge tin deposits, in the midst of an area of normal tin veins, is a vein of somewhat aberrant type known as the Luxer vein.[4] This vein differs from the other veins of the region in that it has not altered the country rock into greisen, and locally the quartz gangue gives place to coarsely crystallized orthoclase intergrown with albite. Violet blue fluorspar is also a prominent gangue mineral. It is thus apparent that this vein stands between the normal tin veins and the Carolina occurrence, a relation pointed out by Beck.

[1] Beck: "Die Lehre von den Erzlagerstätten," 3d ed., 1909, Vol. I., p. 65.
[2] Stelzner-Bergeat: "Die Erzlagerstätten," Vol. I., 1904, p. 23.
[3] Beyschlag-Krusch-Vogt: "Die Lagerstätten der nutzbaren Mineralien und Gesteine," 1910, Vol. I., pp. 343, 442.
[4] J. T. Singewald, Jr.: ECON. GEOL., Vol. V., 1910, pp. 175–7.

These occurrences illustrate, therefore, a complete gradation from the *tin vein type* to cassiterite as a primary constituent in the consolidation of a molten magma.

CONTACT METAMORPHIC DEPOSITS.

Modern genetic classifications place contact metamorphic deposits intermediate between magmatic segregations and veins. The metal content of these deposits was derived directly from the magma. This transfer of material began before the consolidation of the igneous rock set in, and in many cases continued until after the consolidation of the crust of the igneous mass. Such a process must have been of pneumatolytic or at least pneumatohydatogenetic character. In some cases ore deposition continued down to the hydrothermal stage, and ordinary veins are found intimately connected with some contact metamorphic deposits.

The physical-chemical principles involved in the formation of tin veins and contact metamorphic deposits are, therefore, similar; and operate contemporaneously with reference to the various stages in the cooling of the parent magma. But boron and fluorine, the elements so prominent in tin veins, are lacking in most contact metamorphic deposits. Hence, with respect to their mineral assemblage, two widely different types of ore deposits have resulted. Nevertheless it is clear that if a magma which is producing a contact metamorphic deposit contain tin, that tin can be deposited at the same time and a stanniferous deposit result. Further, when we consider that such minerals as fluorspar, tourmaline, and axinite, as well as other boron and fluorine minerals, as datolite, ludwigite,[1] etc., do occur sparingly in some contact metamorphic deposits, we would be surprised if there were no stanniferous contact metamorphic deposits.

In the third edition of his "Lehre von den Erzlagerstätten," 1909, Beck has introduced two new subdivisions into his group of contact metamorphic deposits which he calls the *Schwarzenberg type* and *tin deposits of contact metamorphic origin*. Equiv-

[1] Ludwigite occurs in large masses at one locality, near Dognacska, in Hungary.

alent to these is the group of *cassiterite bearing contact deposits* of Beyschlag, Krusch and Vogt's classification.

The deposit worked by the Bakerville mine[1] in the Herberton district Queensland, Australia, is the purest example of a contact metamorphic tin deposit. The ore occurs in the zone of contact metamorphism between a biotite granite and quartzitic schists, and forms a belt from 10 to 20 m. wide immediately at the granite contact. This ore belt consists of brown cassiterite in a gangue of quartz and minute radial aggregates of dark bluish gray tourmaline. Pyrite and pyrrhotite are present but in subordinate amounts.

At Pitkäranta[2] in Finland is a contact metamorphic deposit with a more complex association of ores, which yielded iron, copper, and tin. A batholith of Rappakiwi granite has contact metamorphosed the calcareous layers of pre-Cambrian hornblende schists. There are two principal ore beds called respectively the "lower" and "upper." The lower bed is characterized by a prominent development of skarn, which consists of salite and garnet. The district is divided into four fields, three of which yielded almost exclusively iron ore. The fourth, which is the most westerly and is situated close to Lake Lagoda, yielded almost all of the copper and tin ore. The ore beds are cut by pegmatite dikes which also carry cassiterite and chalcopyrite. The age sequence of the ores in the beds is (1) magnetite, (2) cassiterite, (3) chalcopyrite; but all were formed during the contact metamorphism. Scheelite, molybdenite, native bismuth, fluorite, and topaz (observed only microscopically) occur sparingly.

At Schwarzenberg[3] in Saxony, the geology is similar to that at Pitkäranta. Calcareous layers in a metamorphic series have been contact metamorphosed with the formation of skarn minerals. According to Beck, the ore minerals are not strictly contemporaneous with the contact minerals. Magnetite is again the

[1] Beck: *loc. cit.*, Vol. I., p. 144.

[2] O. Trüstedt: *Bull. de la Com. Géol. de Finlande*, No. 19, 1907.

[3] R. Beck: "Jahrb. fur das Berg- und Hüttenwesen im Königreich Sachsen," 1902, pp. 51–87; 1904, pp. 56–96.

most important ore, but copper, zinc, and lead-silver ores are also abundant. Tin is not everywhere present, and occurred most abundantly in the mines at Breitenbrunn, in association with fluorspar, apatite, and tourmaline. The ores seem to have been introduced by impregnation from fissures which cut the ore beds, as the richest ore shoots occur along the fissures. At Breitenbrunn the ore bed is cut by tin veins[1] which were probably the source of the tin and its accompanying minerals in the beds. The entire mineralization is, however, closely connected with the contact metamorphism.

A step further removed from the contact metamorphic deposits are the tin ores in limestone in Campiglia Marittima, Tuscany, and in the province of Perak in the Malay Peninsula.

At Campiglia[2] tin occurs in association with limonite, either as a vein filling in schists or as metasomatic replacement of limestone in connection with recognizable fissures. Malachite and pyrite with cassiterite inclusions also occur, and it is probable that the limonite has been derived from the pyrite by the decomposition of the latter. In the present form of the deposit, both contact minerals and the characteristic minerals of the tin group are lacking. Nearby are lead, zinc, and copper sulphide ores in association with contact minerals and fluorspar. Less than two miles from the tin mines is a tourmaline granite, the extension of which below the surface as far as the mines is possible. Bergeat looks upon the deposit in its present form as the gossan of a primary stanniferous sulphide deposit of hydrothermal origin. Certainly to place it among the contact metamorphic deposits, as Beyschlag, Krusch, and Vogt[3] have done, is to give it a rather conjectural position.

At Chongkat Pari[4] in Perak, Malay Peninsula, in addition to the placer tin deposits, which are by far the most important, tin occurs in situ in granite and in limestone. In the granite, the

[1] *Idem.*, 1904, pp. 63–64.

[2] A. Bergeat: *Neues Jahrb. für Min., Geol., und Paleon.*, 1901, Vol. I., pp. 135–156.

[3] Beyschlag-Krusch-Vogt: *loc. cit.*, Vol. I., p. 405.

[4] R. A. F. Penrose, Jr.: *Jour. of Geol.*, Vol. XI., 1903, pp. 146–7, 149–150.

cassiterite occurs in pockets, small veins, and networks of intersecting stringers, associated with quartz, tourmaline, fluorite, pyrite, and arsenopyrite. Less frequent are occurrences in limestone. These consist of impregnations along fissures in the limestone, and carry in addition to the cassiterite, pyrite and arsenopyrite, smaller quantities of chalcopyrite and bornite, and some rhodocrocite. These occurrences in limestone are, therefore, closely associated with characteristic tin veins in granite; but the lack of fluorite and tourmaline, which are present in the veins in the granite, hardly admit of a closer genetic association with the granite than the hydrothermal stage.

The group of occurrences just described show then a gradation from a typical contact metamorphic deposit most intimately related to the parent magma to deposits certainly as far removed as the hydrothermal stage.

In the light of the gradations that have just been traced from one major division of a genetic classification to another, gradations of the *tin vein formation* into other *vein formations* are not remarkable; nevertheless, these gradations are extremely interesting and well worth tracing out.

In one direction, the tin veins grade over into the *tourmaline bearing copper formation.* Though copper sulphides, especially chalcopyrite, are seldom absent from tin veins, in their most typical development, as in the case of most of the Erzgebirge deposits, the veins carry only minute quantities of the copper minerals. But even in some of the Erzgebirge deposits, as for example in the so-called "Kupfergrube bei Sadisdorf" the copper ores become more abundant.

The intermediate position of the Cornwall[1] ores is still more apparent. Briefly stated, the Cornwall deposits differ from the Erzgebirge deposits in their abundance of copper and in the prominence assumed by tourmaline as a gangue mineral at the expense of topaz. The Cornwall veins show a difference in depth due to both secondary enrichment and primary deposition.

[1] Phillips-Louis: "A Treatise on Ore Deposits," 2d ed., 1896, pp. 191–229.

Where the outcrops have been weathered and the gossan thoroughly leached, a vein yielding only tin at the surface will at greater depth yield rich copper ores. It is, however, the primary difference that concerns us here. In many of the mines copper veins became in depth tin veins.[1] Thus the Dolcoath mine, the most important of the region, had in its upper levels copper ores almost exclusively. With increasing depth, the ores carried both copper and tin, and finally passed over into tin ores carrying but little copper. This change took place approximately where the workings passed through the schists into the underlying granite. Though this closer relation of the tin to the granite is not always brought out as sharply as in the Dolcoath vein, it is an unmistakable characteristic of the district.

In this connection may also be mentioned the copper bearing veins of the Dry River Valley in the Herberton district, Queensland. These veins are distinguished from the other veins of the district by the presence of copper ores in considerable amount and by certain aberrant features from the tin vein type. The most important of these is the Lancelot vein, and it will be described as representative of the group.[2] In contrast to the occurrence of the copper in the Cornwall veins, the copper ores in the Lancelot vein occur in irregularly distributed masses of rich ore several meters long and deep and taking up the whole width of the vein. The ore minerals in these masses consist of chalcopyrite, bornite, and chalcocite; and the ore itself may run as high as 20 per cent. Cu and 0.1 per cent. Ag. At a depth of 100 m. the vein takes on in part a banded structure, and the hanging wall portion consists of sphalerite, galena, and arsenopyrite, while the rest of the vein filling consists of cassiterite, pyrite, and quartz. In this respect the vein shows some analogy to the *pyritic lead ore formation*. The characteristic fluorine and boron minerals are lacking, as well as the pneumatolytic alteration of the country rock. These veins, therefore, represent a gradation to hydrothermal veins; and their tin and copper content alone suggest a relationship to the *tin vein-tourmaline bearing copper vein* series.

[1] D. A. Macalister: ECON. GEOL., Vol. III., 1908, pp. 371–2.
[2] Edlinger: *Zeit. für prak. Geol.*, 1908, pp. 276–277.

The best illustration of the end member at the copper end of the series is the Thelemark district[1] in southern Norway. The veins here occur in granite, in schists which the granite has intruded, and in granitic dikes which cut the schists. Pneumatolytic minerals as fluorspar, tourmaline, and apatite are present in the gangue; and the country rock has undergone a greisen-like metamorphism which differs from typical greisen in the scarcity of topaz and lithia mica. The Svartdal veins in this district differ from the rest in that they do not occur in granite, but in quartz mica diorite, and besides copper carry gold. They have, however, also caused a greisen-like alteration of the country rock.

The gold bearing copper veins of Chili[2] show a great similarity to the Svartdal veins and might be briefly mentioned here. They carry in addition to the auriferous copper ores small amounts of molybdenite and scheelite, and as gangue minerals quartz and tourmaline. They are closely related to acidic or moderately acidic eruptives which have undergone tourmalinization along the veins.

The similarity of the various members of this *tin vein-tourmaline copper* series has been concretely stated by Vogt[3] in that he calls the tourmaline bearing copper ore veins, tin veins in which copper takes the place of tin. The whole series is characterized by the presence of pneumatolytic minerals and by pneumatolytic alteration of the wall rock. The transition is purely a chemical one. Copper has gradually replaced tin and tourmaline has become prominent at the expense of topaz.

STANNITE VEINS.

I wish next to take up a very unusual type of tin deposit, namely, that in which stannite, a sulphide of tin, occurs as an ore. In all the deposits considered up to this point the tin ore occurs solely in the form of the oxide, cassiterite (SnO_2). For the sake of simplicity, stannite may be looked upon as chalcopyrite in which one half of the iron is replaced by tin and the formula may

[1] J. H. L. Vogt: *Zeit. für prak. Geol.*, 1895, pp. 149–153.
[2] Stelzner: *Idem.*, 1897, pp. 41–53.
[3] Vogt: *Idem.*, 1895, p. 149.

be written $CuFeS_2 \cdot CuSnS_2$. Though found in many tin deposits as a mineralogical curiosity, it is thus far known in sufficient amount to be considered one of the ore minerals in only two districts in the world. These are the Cerro de Potosi district in Bolivia and the Mt. Zeehan district in Tasmania.

In the decade preceding his death, Stelzner became especially interested in the rich silver veins of Bolivia which also carried a large amount of tin. Though he never visited the district he thoroughly worked up the literature on that portion of South America, and supplemented this information with an extensive correspondence and a careful study of specimens sent to him by his correspondents in Bolivia. In 1892 he made a preliminary statement before the German Geological Society; but it was not until 1897, soon after Stelzner's death, that Bergeat published the detailed discussion of his results in the shape of a partially unfinished manuscript.[1] The lack of personal acquaintance with the field makes some imperfections in this work inevitable, nevertheless it stands today as the most valuable description that we have of these extremely interesting deposits. Stelzner starts out by calling attention to the prevalent idea that tin veins occur over the whole earth not only under uniform geological conditions, but also show uniform mineralogical properties. The Bolivian veins he says are characterized, however, by the simultaneous occurrence of tin ore with silver and lead ores, and by the complete absence of the boron and fluorine silicates. (Since Stelzner's time these minerals have been found in small quantity in the deposits described by him.)[2] These veins presented, consequently, such a departure from the normal tin veins that he emphasized the statement that the most, *but by no means all,* tin deposits over the whole earth show uniform geological and mineralogical features. These Bolivian veins he designated the *Typus Potosi,* and in "Die Erzlagerstätten" of Stelzner-Bergeat this type appears as a separate group under the name *Silberzinnerzgänge.*

This *Typus Potosi* occurs over an extensive area on the high

[1] Stelzner: *Zeit. der deut. Geol. Gesell.*, Vol. XLIX., 1897, pp. 51–142.
[2] W. R. Rumbold: Econ. Geol., Vol. IV., 1909, pp. 321–364.

plateau of Bolivia, extending from latitude 15° S. to 21° S. The characteristics emphasized by Stelzner are that the veins are connected with dacites and quartz trachites which were erupted in early Cenozoic time and not with granites. The nearest granites are from 170 to 520 km. from the deposits, with the exception of a small occurrence of tourmaline granite of much greater age than the veins. The usual pneumatolytic minerals, tourmaline. topaz, fluorspar, and apatite, are absent. The tin occurs as both oxide and sulphide, that is, as cassiterite and stannite. As cassiterite it is enclosed in the form of microlites in the other sulphides, and occurs also in massive form in association with much pyrite. The veins are remarkably rich in silver especially in the enriched zones. The silver occurs chiefly in association with tetrahedrite. In the oxidized zone enormous masses of secondary cassiterite, called from its appearance "wood tin," occurred together with great masses of secondary silver ores. The latter were mined long ago and gave Bolivia its great renown as a silver producing country. Besides the tin and silver ores, lead, zinc, copper, bismuth, and antimony ores are prominent in different parts of the region. The presence of rare germanium minerals, as argyrodite and franckeite, also adds renown to the region. The silver and tin ores are so intimately intergrown, that it is impossible to separate them by hand sorting, and the tin is obtained from the residue after the silver has been extracted by roasting and amalgamation. Stelzner concluded from his study of the ores that the tin minerals and the silver-bearing minerals were deposited simultaneously, and that it was not possible to hold the view that tin veins were formed first, and subsequently reopened and the silver minerals deposited. Hence the tin ores of these veins must have been formed under hydrothermal conditions and not pneumatolytic. The features just described seemed to him to sever completely these veins from the tin vein type.

In 1907, Steinmann,[1] who personally visited the deposits, called attention to the fact that just northeast or east of the veins described by Stelzner, are veins in lower Silurian schists which

[1] Steinmann: *Zeit. der deut. Geol. Gesell.*, Vol. LIX., 1907, pp. 7–9.

show a simpler composition—quartz with cassiterite and pyrite, and complete absence of the complex silver ores. Steinmann still clung close to Stelzner's view in interpreting their relation to the *Potosi type*. He considered an original differentiation of the mineral bearing solutions to have taken place. The one phase, which was the more closely connected with the liparites and dacites, deposited the ores of the *Potosi type;* the other deposited at a greater distance from the eruptives the pure tin veins which he called the *Araca type,* from their occurrence at Araca. Beck[1] agrees with this interpretation.

Rumbold,[2] in his article on the origin of Bolivian tin deposits, brings out points of similarity between these deposits and normal tin veins and concludes that their origin was the same. The only distinguishing characteristic he finds in these veins is the presence of silver.

In a recent number of the *Annales des Mines,*[3] M. Armas discusses at some length the Bolivian tin deposits. He strongly attacks Stelzner's position and comes back to the pneumatolytic origin of the tin deposits as the only tenable explanation.

He brings out the fact that there are two zones of tin deposits in Bolivia, having a northwest direction and lying about 60 km. apart. The southwesterly zone includes the most important deposits, Oruro, Potosi, Chorolque, etc., and is associated with young eruptives. The northeasterly zone, within which Araca is situated, lies in great part in ancient schists and quartzites. The tin veins Armas says have all derived their tin from the same source, that is, from a deep lying acid magma of great extent with apophyses which show here and there in the mineralized region as dikes and intrusive masses. To substantiate his views Armas describes in detail many of the deposits, but principally those of the northeastern zone with which he is better acquainted. In this belt he describes stanniferous pegmatite dikes and veins closely associated with pegmatite dikes carrying pneumatolytic minerals. The mention of the southwesterly zone, in which

[1] Beck: "Die Lehre von den Erzlagerstätten," 3d ed., 1909, Vol. I., p. 310.
[2] W. R. Rumbold: *loc. cit.*
[3] M. Armas: *Annales des Mines*, 10th Ser., Vol. XX., 1911, pp. 149–213.

the principal silver bearing veins occur, is very brief; but he regards the introduction of all the other ores to have taken place by means of hydrothermal solutions, subsequent to the formation of the tin ores, as a result of a reopening of the veins.

Although Armas strongly attacks Stelzner's view, he excuses him on the ground that most of the veins he describes were not known in Stelzner's time, and that had Stelzner been familiar with them he would have modified his views.

Though still not as reliable or as thorough as one might wish, the information we have in regard to this district indicates that neither Rumbold and Armas on the one hand, nor Stelzner on the other, are wholly right. In one portion of the field it seems that pneumatolytic tin veins with the normal associations of such veins exist; in other portions, we have tin bearing veins of hydrothermal origin in which the tin has in part been deposited in the unusual form of stannite. Further exploration in this little known region will doubtless bring out the relation of these two types more clearly, and show that the gradational steps away from an igneous source are from *Typus Araca* to *Typus Potosi.* Such a relation is far more probable than the gradation from *Typus Potosi* to *Typus Araca,* suggested by Steinmann and endorsed by Beck, which is entirely at variance with the accepted views as to the origin of tin veins. This view is also rendered the more probable in the light of recent investigation in the Zeehan district.

In a bulletin on The Ore Bodies of the Zeehan Field, Twelvetrees and Ward[1] have given a comprehensive discussion of the genetic interrelationships of the Zeehan field and surrounding territory. In the Zeehan field proper is a Silurian complex of slates, sandstones, and conglomerates with intruded dikes and beds of malaphyre and malaphyre tuffs, and some gabbro and serpentine. To the west lies the Devonian Mt. Heemskirk granite massive. This brief geological sketch is all that is necessary for the present purpose.

Within this region, several different types of ore deposits

[1] W. H. Twelvetrees and L. K. Ward: Bull. 8, Depart. of Mines, Tasmania, 1910.

occur, which are arranged areally in three zones, termed respectively, the Granite Zone, the Contact-Metamorphic Zone, and the Transmetamorphic Zone.

Within the borders of the Mt. Heemskirk granite are a number of ore bodies carrying chiefly cassiterite, and less abundantly wolframite, native bismuth and molybdenite. Associated with these are tourmaline and pyrite. Isolated occurrences of similar veins extend out into the transmetamorphic zone.

The contact metamorphic zone is the most well defined, simple, and narrow of the three principal zones. The most prominent ore of this zone is magnetite. Some magnetite occurrences are practically free from sulphides; in others the sulphides of lead, zinc and copper are very prominent. The point of chief interest to us in this zone is the occurrence, in one instance at least, of an admixture of cassiterite and magnetite.

In the transmetamorphic zone, the prominence of the oxide ores disappears, and with few exceptions the primary metallic minerals occur as sulphides. In this zone, the authors have distinguished two main divisions. In one of these, the predominant gangue mineral is pyrite; in the other siderite. In areal distribution, the pyritic veins form an inner belt, the sideritic an outer belt, with reference to the granite massive. The dividing line is naturally not sharp and transitional types occur. The principal sideritic veins carry galena, though a few nickel-silver veins are known.

The pyritic group is further subdivided into the galena type and the stannite type. The galena type, in addition to the pyrite may or may not carry sphalerite. Some of the veins of the stannite type carry chalcopyrite, in addition to pyrite, in association with the stannite; others carry galena. Small quantities of wolframite and bismuthinite occur in these veins. The cupriferous stannite veins are also argentiferous, and were for a long time worked chiefly for their silver and copper, no payment being made for the tin. Since 1901, a contract has been in force providing for payments for the tin in the stannite when the ore ran above 8 per cent. Sn. The average content of the stannite ores

since then has been 9 per cent. Sn. At the principal occurrence of the stannite veins, one of the pyrite cassiterite veins of the granite zone type has been discovered.

The foregoing description suffices to bring out the genetic relationships of the ore deposits of this region. The gradation passes successively from cassiterite veins in granite, to contact metamorphic deposits in which cassiterite has been found, to sulphide veins, some of which carry tin sulphide, to sulphide veins with a carbonate gangue. Expressed genetically, the gradation is from pneumatolytic in a solidified portion of the parent magma, to pneumatolytic at the contact with the parent magma, to pneumatohydato-genetic or hydrothermal, to more pronouncedly hydrothermal. Since this transition, which has been traced horizontally, is not essentially a horizontal function, but rather a function of absolute distance from the parent magma, and since the Mt. Heemskirk granite probably continues across the Zeehan field at an unknown depth below the surface, the authors suggest that the same gradation would probably be found if one could go down vertically from the outer belt of the transmetamorphic zone until the granite was encountered.

The Zeehan field, and less perfectly the Bolivian tin region, the only known occurrences of stannite in relatively large quantities, bring out admirably, therefore, the transition from the magmatic phase to the pure hydrothermal phase in the formation of ore deposits.

In the foregoing discussion, little or no emphasis has been laid upon the almost constant association of tungsten with tin, and the very frequent association of bismuth ores in considerable amount with tin. In the case of both of these metals, transitions can be traced from pure tin types to pure types of either of them. Also taking up each of these metals separately, similar transitions from one genetic type to another can be traced as have been traced in the case of tin. To have done so would have been beyond the scope of the present paper, in which it was intended to deal primarily with tin ore occurrences.

The genetic relations of tin deposits brought out in the pre-

Phases.	Via Pegmatitic.	Via Contact Metamorphic.	Via Tin Vein-Tourmaline Copper Vein.	Via Stannite Veins.	
Magmatic	Cassiterite in granite	Cassiterite in granite			
				Bolivia	*Mt. Zeehan*
	Etta Knob				Tin veins in granite
	Carolinas	Bakerville			
Pneumatolytic		Pitkäranta		Typus Araca	Contact metamorphic
	Luxer Vein		Erzgebirge		
			Sadisdorf		
			Cornwall		
			(Dry River Valley)		
	Erzgebirge	Schwarzenberg	Thelemark		
			Chili		
Hydato-pneumatolytic					
				Typus Potosi	Pyritic veins with stannite
		Campiglia			
Hydrothermal		Perak			Sideritic

ceding pages are compactly summarized in the accompanying table. In the first column are placed the phases under which the deposits have been formed, starting with the magmatic phase and passing down to the hydrothermal. Transitions have been traced along four main lines, and each of these is represented by a column parallel to the first column. These four columns may be regarded as the routes by which the transitions have taken place. The examples in each column are then placed as nearly as possible opposite to that phase in the first column to which they correspond. This arrangement shows at a glance the inter-relationships of the deposits which have been discussed.

NOTES ON THE GEOLOGY OF THE MINA MEXICO VEIN.

DIBRELL P. HYNES.

LOCATION AND TOPOGRAPHY.

The Mina Mexico is situated in the Sahuaripa district of Sonora, about ten miles southward from the town of Bacanora and two miles west of the Bacanora River. It is northeast of and thirty miles distant from Tonichi, the terminus of the Yaqui River Branch of the Southern Pacific Railway.

The property lies among low hills on the eastern side of a divide which separates the Bacanora River from a tributary. The hills are rugged and irregular, rising to elevations of 3,500 feet, about six hundred feet above the Bacanora and three hundred feet or more above the beds of the smaller streams. The summits of the neighboring ranges attain elevations of nearly 6,000 feet. Rain is abundant for two or three months, but the rest of the year is dry.

GEOLOGY.

The area is underlain by a conformable series of sedimentary rocks some thousands of feet thick. A prominent member of the series is a black, sub-crystalline limestone which is pure enough to be used for flux. (CaO 50 per cent., SiO_2 4 per cent.) The other formations are light colored, siliceous, calcareous rocks of very fine grain. The whole series is tilted forty to fifty degrees, with a prevailing strike to the northwest and a dip to the northeast.

The rocks are much fractured and small dislocations are numerous. The area is affected by faults of considerable magnitude, some of which displace the vein.

Several miles southwest of the mine, granitic rocks are found. and the sedimentary series seems to dip away from them. The relations were not studied in detail.

In the vicinity of the mine and elsewhere the valleys of the Bacanora and its tributaries expose beds of consolidated conglomerate one hundred feet or more in thickness. The youngest beds are horizontal, or nearly so; but the older beds are steeply inclined. The conglomerate is unconformable on the older sedimentaries and is apparently developed only in the valleys of the present streams. This formation contains, in places, one or more flows of igneous rock, probably andesite. It is evident, from the fact that the older beds have been deformed, that part of the diastrophism which has affected the region occurred in recent times.

THE MINA MEXICO VEIN.

Though several veins have been prospected, this is the only one in the locality which has been extensively worked. It was exploited by a Mexican company during the last twenty-five years, but is now in the hands of an American company which is treating the ore in a blast furnace and shipping copper matte rich in silver.

The vein conforms closely in strike and dip with the strata of the enclosing sedimentary formation, a light-colored, siliceous, calcareous rock which contains numerous small dendrites of iron oxide. Its strike is northwesterly, dip, forty-five degrees to the northeast.

The deposit has been developed in the mine workings for a distance of 2,900 feet along the strike and 800 feet along the dip. In width it varies from a few inches to two feet, averaging less than a foot. The outcrop, where exposed, is marked by iron stain, and does not rise above the country. Oxidation extends to depths of less than fifty feet on the vein, though the present ground water level, which may have been depressed by the deep mine openings, is from two hundred to three hundred feet below the outcrop, measured on the incline. The mine makes a considerable quantity of water, though the vein carries little.

The walls are quite sharply defined and generally do not carry gouge. The ore, as it is broken from the walls, has plane surfaces, usually, though not always, without slickensides. Knife

blade stringers of ore, mostly lean, occur in the adjacent country rock.

By examination of thin sections the wall rock is found to consist largely of microscopic grains of quartz with chlorite, kaolin, and shreds of calcite. Cubes of pyrite, large enough to be discernible megascopically, are irregularly distributed. Minute cracks are occupied by chlorite and kaolin with a little calcite. Evidently the effect of the mineralizing solutions has been to render the rock more siliceous and to introduce a small quantity of pyrite. There is nothing to indicate replacement of the country rock by ore.

The minerals of the vein are pyrite, quartz, blende, galena, calcite, and tetrahedrite. The analysis of the ore shows the presence of arsenic, which probably occurs in an isomorphous mineral with the tetrahedrite. The ore is compact and dense, contains a greater proportion of metallic minerals than of gangue. No open spaces were observed.

The vein exhibits distinct, but not uniform, bands ranging from a fraction of an inch to several inches in thickness. An individual band may consist predominately of one mineral, but also contains variable quantities of other minerals, and grades into the contiguous bands. The character of these bands is not persistent, nor are they developed in pairs. In some places the vein matter is divided by several inches of barren country rock, which, though it may be frozen to the ore, is separated from it by definite boundaries. Here and there the quartz has developed crystals whose elongations are perpendicular to the walls, thus showing an approach to crustified structure.

Where blende, galena, and calcite are present in quantity the banding is not evident, as these minerals occur in patches of considerable size.

The vein is stoped in stretches which sampling shows to be of profitable grade. Assays of a few ounces to two hundred ounces of silver per ton are obtained from samples taken within a few feet. There is no essential difference between the ore developed on the upper and on the lower levels.

The silver content is roughly proportional to the quantity of tetrahedrite.

MICROSCOPIC STUDIES.

Thin sections of the lean quartz of the vein and polished sections of the opaque ore were prepared for microscopic examination. In the latter work, the suggestions made by William Campbell, ECONOMIC GEOLOGY, Vol. I., were followed.

The sections described below exhibit the principal characteristics of the ore.

No. 1. Specimen from the 700-foot level, thin section from band of lean quartz. The opaque bodies are metallic minerals, among which may be identified pyrite and blende. The quartz has uniform extinction and normal interference figures. The microphotograph shows the pyramidal termination of a quartz

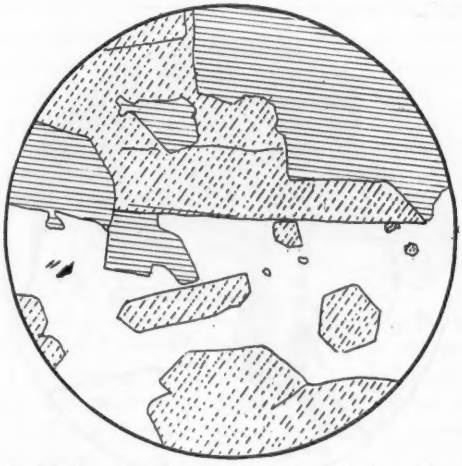

FIG. 35. Polished section of ore. Vertical illumination. Magnification, 80 diameters. Pyrite, quartz, and tetrahedrite.

crystal defined by opaque mineral particles. This crystal and others parallel to it are developed with their long axes perpen-

dicular to the band, an arrangement which approaches crustified structure.

No. 2. Specimen of ore from the 700-foot level. Pyrite, quartz, and tetrahedrite are intergrown. Sections of quartz crystals oriented in all directions can be seen (Fig. 35). It will be noticed that the quartz occurring in the tetrahedrite is automorphic, while that intergrown with pyrite is hypautomorphic.

No. 3. Specimen of ore from 700-foot level. Pyrite shows in well formed cubes developed against both quartz and tetrahedrite. Quartz within the tetrahedrite is euhedral.

No. 4. Specimen of ore from the 500-foot level. Quartz is included within tetrahedrite, which is in turn surrounded by pyrite. Pyrite and quartz show crystal boundaries, but tetrahedrite, as in the case of the sections previously described, is without crystal form.

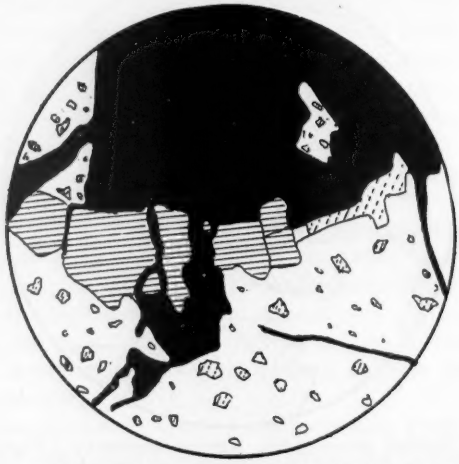

FIG. 36. Polished section of ore. Vertical illumination. Magnification, 20 diameters. Pyrite, quartz, tetrahedrite, and blende. In the drawings of the ore sections, the minerals are lettered as follows: Pyrite, *p;* quartz, *q;* tetrahedrite, *t;* blende, *s.*

No. 5. Specimen from bottom of 60-foot winze on the 700-foot level, section from patch of blende. The pyrite, quartz, and tetrahedrite, which bear the same relations to one another as in the preceding specimens, occur in small irregular aggregates entirely surrounded by blende. The drawing (Fig. 36) shows blende enclosing the other minerals and occupying cracks within them. Calcite is found associated with this blende.

Within the quartz of some of the sections examined by reflected light, a high power reveals the presence of a gray, metallic mineral occurring in fine acicular crystals, sometimes in radiating groups, which is thought to be stibnite.

Tetrahedrite was observed enclosed within an automorphic quartz individual which was itself imbedded in tetrahedrite. Isolated cubes of pyrite and xenomorphic masses of tetrahedrite were noted within quartz.

In all the sections the proportion of tetrahedrite to the quartz occurring as automorphic crystals within it is approximately constant, indicating that this proportion may be a eutectic.

Microscopic veinlets of quartz, carrying pyrite, which cut through pyrite, quartz and tetrahedrite, are not uncommon.

Galena with calcite was observed in much the same relation to the other minerals as the blende of No. 5.

PARAGENESIS.

From the foregoing, certain deductions in regard to the paragenesis of the ore seem warranted.

The minerals are found to be associated in two groups: Group I.: Pyrite, quartz, tetrahedrite, a little blende and galena, and stibnite (?). Group II.: Calcite, galena, and blende. Galena and blende are much more abundant in the second association than in the first. A small amount of quartz is associated with the second group.

The first group is considered to be a primary deposition from a magmatic solution. The order of crystallization prevailing is:

Pyrite,
Quartz,
Tetrahedrite.

Blende and galena of this group were probably crystallized along with pyrite. Subsequent fracturing on a small scale permitted quartz with pyrite to enter openings in the previously consolidated minerals.

Reopening of the vein and fracturing preceded the precipitation of the second group, which is evidently of later origin than the first. From the solution which was responsible for the first group, that which deposited the calcite, blende, and galena must have differed essentially, and it is possible that meteoric waters had a part in the deposition of these minerals.

CONCLUSION.

Evidently the deposit belongs to the type classed as fissure veins; and it was probably formed under conditions of moderate to shallow depths. Since it was formed subsequently to the tilting of the beds and prior to the latest disturbances of the region, it is likely that the deposition took place during the late tertiary epoch of metallization, as defined by Lindgren, ECONOMIC GEOLOGY, Vol. IV., p. 411.

The characteristics of the deposit are such as to indicate its origin from magmatic solutions, though no association with igneous rocks was established. The possible influence of meteoric solutions on the formation of the blende-galena-calcite group is to be considered.

Among the primary minerals tetrahedrite must surely be classed, as its associations establish the fact that it was crystallized from the solution along with pyrite and quartz. Argentiferous tetrahedrite, in a different association, has been classed as a primary mineral by Irving and Bancroft.[1] It is also considered a primary mineral at Cripple Creek.[2]

[1] Bulletin 478, U. S. G. S.
[2] Professional Paper No. 54, U. S. G. S.

NOTES ON THE BLUE BIRD MINE.

H. V. Winchell and A. N. Winchell.

Peculiar interest attaches to the Blue Bird Mine and the adjoining property called the Penn Yan, because of the mineralogical association, which is not common, and the presence of a great abundance of tourmaline. The following account is based upon examinations made at various times during 1911 by the authors. The particulars relative to the physical appearance of the property, the general geology and past history are contributed by the senior author, while the more technical mineralogical and petrographical descriptions were furnished by the junior author.

The Blue Bird Mine is situated three and one half miles directly west from the town of Wickes, Montana. The mining claims occupy the central portion of Section 13, Township 7 North, Range 5 West, Jefferson County, Montana. The elevation at the mine is about 7,000 feet above the sea, and from the summit of the property an uninterrupted view is had of the Missouri River basin upon the north, the Elkhorn Mountain upon the east and a large stretch of territory to the southwest.

This mine and the Penn Yan have been known and intermittently operated for many years. Ore has been taken from them at different points and upon different occasions by various former owners and lessees. The aggregate value of the ore thus produced probably exceeds a quarter of a million dollars. Between 1887 and 1893 the mine produced about one thousand tons of ore containing an average value of about 0.56 oz. of gold and 65 oz. of silver per ton. There is a marked difference in the metallic content of different ore shoots. The Blue Bird ore proper contains excellent silver values but only a fraction of the amount of gold contained in the Penn Yan ore. To how great an extent this apparent difference is explained by the greater depth of the workings upon the Blue Bird is uncertain.

It should perhaps be mentioned that these properties are in a district which was formerly famous as the home of several important mines. The Alta Mine near Corbin has been idle for many years, but is again being put into condition for operation. Several other properties in the immediate vicinity have at one time or another made important contributions to the precious metal production of Montana.

The particular development through which the mine can be studied at the present time is in the nature of a tunnel cross-cutting the country rock for a distance of nearly 600 feet to the vein which it then follows more or less closely throughout the length of the Blue Bird and into the Penn Yan claim. Just west of the middle of the Blue Bird claim is a shaft about 200 feet deep from the tunnel level, thus reaching a depth of about 600 feet from surface. Here there is developed an ore shoot which appears to have a pitch or rake in the vein to the west. In mining parlance the ground is heavy and requires unusually strong timber support. The ore from this mine is hauled to the railroad and then shipped to the smelter in Butte. A second ore shoot has been developed in the Penn Yan farther to the west.

The rocks which occur in the vicinity of this mine are granite, dacite (and latite), and andesite-porphyry and slate. The principal vein appears to follow closely the contact between the granite and slate. This vein varies in thickness from a few feet to more than thirty feet. It evidently marks the plane of considerable faulting movement and has been much crushed. There has also been a faulting within the vein since the deposition of the ore. The vein strikes easterly and westerly and has a nearly vertical dip. The ore is frequently found within the vein at some little distance from the actual contact. At such times it has slate upon both walls.

The vein minerals include quartz, tourmaline, pyrite, tetrahedrite, rhodochrosite, galena, sphalerite, chalcopyrite, arsenopyrite, malachite. In places the vein is almost wholly filled by tourmaline; elsewhere this mineral is intimately intergrown in large amounts with quartz, pyrite, and other sulphides. The

tourmaline also extends into the granite in places; more rarely it extends into the slate.

Occasionally there is a rich segregation of galena ore carrying excellent silver values, but normally the ore mined contains its principal values in silver and copper. In respect to the valuable metallic contents, therefore, this vein is different from the ordinary tourmaline gold-copper veins mentioned by Lindgren,[1] although in general the origin of the mineralization must be similar.

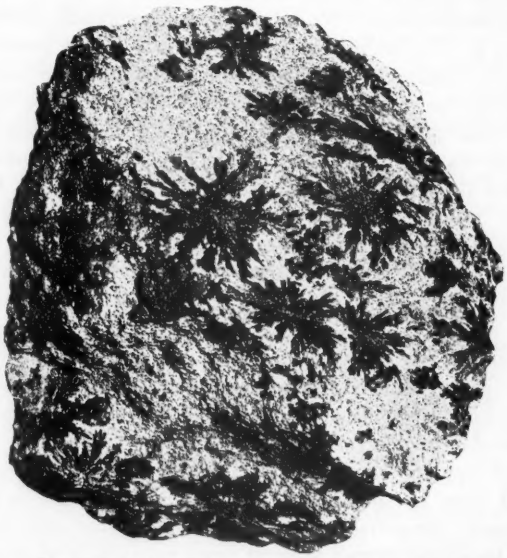

FIG. 37. Photograph of sample of tourmaline-bearing ore from the Blue Bird mine, Jefferson Co., Mont. The tourmaline is in coarsely radiated aggregates in a matrix of euhedral pyrite and anhedral quartz. About one half natural size.

The occurrence of the tourmaline is quite striking, particularly where it contains a portion of the vein material or is mingled with the ore. This is well illustrated by Fig. 37. On the other

[1] "Metasomatic Processes in Fissure Veins," *Transactions A. I. M. E.*, Vol. XXX., 1900, p. 626.

hand, where it occurs in fractures in the country rock and in the unmineralized portion of the vein, it is frequently in the form of delicate spicules or hair-like aggregates, lying criss-cross in the usual manner of tourmaline needles and apparently of later origin than the fracturing and crushing of the rocks. There are also instances in which the tourmaline has been much crushed and the resultant product is a black, pulpy mass in which the individual tourmaline needles have been disguised or completely lost so far as can be seen by the naked eye.

The distribution of the ore in the vein is sporadic and cannot be seen to have an immediate connection with the presence or absence of tourmaline. There is not upon the other hand any distinct evidence of different periods of deposition for the sulphide minerals and for the tourmaline. The evidence tends generally to support the theory that the period of tourmalinization was also the period of the sulphide mineralization. In this respect it does not seem to correspond precisely to the gold-bearing lode of Passagem described by Derby.[1]

Although there is not sufficient development at the Blue Bird Mine to justify any conclusions as to the depth to which ore deposits are likely to extend, and although the ore shoots are no more irregular here than in many other mines, yet the impression made upon the mind of the geologist by the phenomena observed here and elsewhere is not distinctly favorable to tourmaline as an associated vein mineral. It would appear that possibly conditions of deep mineralization are not so favorable for the deposition of large and important deposits of valuable ore as conditions nearer the surface. It may be also true that such deposits which have been formed at great depth may not be so accessible to the influences and forces which bring about secondary enrichment and deposition as ore deposits which were primarily formed above the zone of tourmalinization.

These rocks and ores deserve somewhat detailed description. The granite is presumably a local phase of the Boulder quartz monzonite batholith. It contains dominant orthoclase with some

[1] *American Journal of Science*, September, 1911, p. 185.

plagioclase. Quartz occurs in abundant micrographic intergrowth with orthoclase. The ferromagnesian minerals present include biotite, hornblende and magnetite, with secondary chlorite and epidote. The other minerals present include muscovite, titanite, zircon, and apatite.

Some samples of granite differ considerably from the normal type. They are much more siliceous, containing abundant free quartz. They also contain abundant orthoclase and some plagioclase, partly altered to sericite and calcite. A few phenocrysts, apparently of plagioclase, are now almost wholly altered to sericite. Such samples also contain tourmaline and pyrite. In containing tourmaline these rocks are related to pegmatites, while the presence of the phenocrysts relates them to granite porphyries. The pyrite is apparently a later introduction due to mineralization.

The dacites contain phenocrysts of quartz, plagioclase, biotite, and orthoclase in a ground-mass of about the same composition. There are also a few small phenocrysts of hornblende and small crystals and anhedra of titanite. The quartz phenocrysts are all rounded and have indistinct embayments. The plagioclase is a zonal andesine. Some of the biotite lamellæ are distinctly bent. Well-formed crystals of zircon, apatite needles, and very small magnetites are distributed through the rock. Some samples show fewer phenocrysts, more magnetite, and more alteration to calcite, chlorite, sericite, rutile, etc. In some cases the quartz is rounded by partial resorption.

One sample approaches a rhyolite in composition, but is probably better described as a latite. It contains phenocrysts of plagioclase and orthoclase and rarely of quartz. The rock has been notably altered by hot solutions, but shows very little alteration due to cold solutions. It is impossible to state the original nature of the ferromagnesian constituent as it is now entirely replaced by chlorite, but the indications of form point toward hornblende. A remarkable feature is the apparent partial alteration of chlorite to sericite. The feldspars are also considerably altered to sericite and calcite. Other constituents include ilmenite, titanite, leucoxene, rutile and small grains of secondary quartz.

The andesite porphyry contains large phenocrysts of plagioclase with smaller ones of biotite, in a granitic groundmass. Orthoclase is present in rare phenocrysts and more abundant smaller crystals. Biotite is largely, and another mineral (hornblende?) wholly altered to chlorite. The accessory minerals include magnetite, apatite, and titanite. Epidote is remarkable for its freshness in a rock considerably altered. Minute alteration products seem to include sericite, chlorite, epidote, and magnetite.

The slate of the region is highly metamorphosed and has been regarded locally as a modified andesite. Its character as a slate is believed to be established by the following considerations:

1. The rock varies radically in composition, from a basic rock resulting from the contact metamorphism of an ordinary clay slate to a highly quartzose rock produced by recrystallization of a sandy shale.

2. The texture also varies from that of a metamorphosed slate to the globulitic[1] or "contact" type.

3. Even in the basic phases of the slate quartz occurs sparingly.

4. In rare instances the quartz grains, although enlarged by secondary growth during metamorphism, show the rounded outlines of the sedimentary state by dust-like particles still in position on the former surface of the grain.

5. In spite of the presence of large crystals (pseudophenocrysts) of plagioclase and irregular patches of hornblende enclosing magnetite, the rock shows no true igneous texture. It is believed that both the plagioclase and the hornblende are of metamorphic origin like the garnets produced in schists. Experiments at the Geophysical Laboratory recently have shown that magnesian amphibole may be produced from suitable materials in the presence of water under pressure at temperatures below those of rock fusion.[2]

6. Zircon, on account of early crystallization, is nearly always in well-defined crystals in igneous rocks. When igneous rocks break down zircon crystals become rounded and lusterless. When

[1] A. N. Winchell: *Bull. Geol. Soc. Amer.*, XX., 1908, p. 666.
[2] *Amer. Jour. Sc.*, XXII., 1906, p. 403.

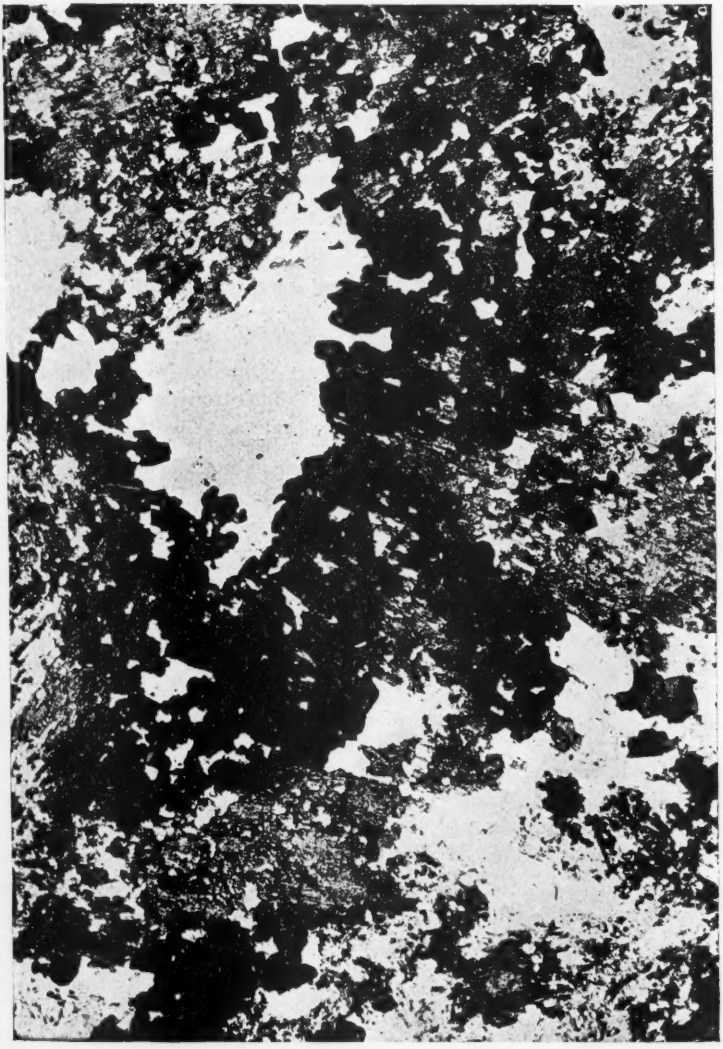

FIG. 38. Photomicrograph of thin section of tourmaline-bearing ore from the Blue Bird mine, Jefferson Co., Mont. The white mineral is quartz; the gray mineral is tourmaline; the opaque mineral is pyrite. Note the intimate intergrowth of the three. One nicol. × 38.

either igneous or sedimentary rocks are anamorphosed the zircon crystals are so small and so stable that their forms remain unmodified in nearly all cases.[1] Zircon is too heavy to be abundant in muds and shales; nevertheless a few crystals are present in these slates, and they are well rounded and lusterless in every case.

The ores commonly consist of tourmaline, quartz and pyrite in varying amounts with or without subordinate quantities of other sulphides such as sphalerite, chalcopyrite, galena. The vein-filling is nearly pure tourmaline in places; elsewhere it is highly quartzose, or composed largely of sulphides; in some places these constituents are intimately intergrown in approximately equal amounts. Sericite occurs in some samples, but in general it is not abundant. Part of the pyrite is of later formation than the tourmaline, but in part also the two are so intergrown as to appear to have been contemporary in crystallization. This is distinctly shown in Fig. 483.

The development of radiated aggregates of tourmaline on a large scale in the midst of sulphide ore is shown in Fig. 484.

In hand samples the tourmaline seems to be all of one type, black and nearly opaque. But in thin section it is readily seen that two types are present with gradations between them. These two types differ in color, pleochroism and birefringence as follows:

	Blue.	Brown.
$Z(O)$	= slate blue	to dark brown.
$X(E)$	= pale yellow	to brownish yellow.
$n_g - n_p$	= 0.020 ±	to 0.030 ±.

[1] J. D. Trueman: Thesis for doctor's degree, University of Wisconsin, 1911.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

CRITERIA FOR REPLACEMENT ORE BODIES.

Sir: J. D. Irving's paper on "Replacement of Ore Bodies and Criteria for their Recognition" has but recently come to hand and I have welcomed it, as must every other mining engineer, as an important and valuable contribution to the subject. But because of this very fact and the weight of Professor Irving's name, I feel bound to challenge a statement which has been so often repeated as to become almost traditional.

On p. 532 of ECONOMIC GEOLOGY (Sept., 1911) Professor Irving remarks:

> "He will also be concerned chiefly with these ore deposits in which replacement has been a preponderant process and cavity filling has been only subordinate. *As such deposits are more common in limestone formations than elsewhere,* the paper will of course, deal more largely with them than with any other types."

And again on p. 560:

> "Pure or fairly pure limestones, being composed of aggregates of calcite or dolomite grains with comparatively little other material, and that scattered widely through the rock, *are far more extensively and completely replaced* than any other type of rock."

Also in that paper, a table is given representing the dimensions of the larger ore bodies replacing limestones in this country.

A review of the great pyritic ore bodies of the world will, I think, refute the assertion that limestone lends itself to more com-

plete replacement by metallic sulphides than siliceous rocks and that larger and more important ore bodies result from replacement of the former than of the latter. Let us consider but three types of massive pyrite deposits which occur as replacements in rocks high in silica. Foremost amongst them comes a great group of the largest pyrite masses hitherto discovered, those in the province of Huelva in Spain. One of these measures over 3,000 feet in length, with a maximum width of 600 feet and has been proven to a depth of 1,500 feet. These ore bodies occur under various conditions and their genesis is probably not uniform, but at all events many of the larger deposits have been determined as metasomatic replacements of a quartz porphyry containing 75 per cent. silica. The replacement of this material by metallic sulphides is virtually perfect since only 2 per cent. or less of silica remains in the ore.

In Shasta County, California, some of the greatest deposits, containing each over 1,000,000 tons of ore, occur as replacements of alaskite containing over 70 per cent. silica. Here again the residual silica of the massive pyrite is negligible.

In the Ural Mountains, ore bodies of the order of a million tons each have been developed. These are replacements along shear zones in talc and chlorite schists. A composite analysis of many samples will demonstrate the thoroughness with which the massive pyrite bodies of this region have replaced the schists.

	Per Cent.
Cu	4.10
Fe	40.61
S	47.30
Pb	.18
Zn	1.60
BaO	2.56
CaO	.22
MgO	.30
Al_2O_3	1.52
SiO_2	.56
As	.12
	99.07

These are but a few of the instances which will be called to mind and are sufficient to suggest that under deep-seated thermal conditions siliceous rocks are at least as readily subject to replacement by metallic sulphides as limestone.

H. H. KNOX.

THE TEACHING OF ECONOMIC GEOLOGY.

Sir: I was glad to see, in the October–November number of ECONOMIC GEOLOGY, the article on "The Teaching of Economic Geology to Mining Engineers" by Mr. C. A. Stewart, and I fully agree with his views as to the relatively lower emphasis that should be placed on detailed descriptions of mining districts, in the ordinary undergraduate course. My own experience in teaching this subject has convinced me that the things of real importance to the mining student in a study of ore-deposits are the more general facts and principles. These are the things which he is most likely to remember when his university work is finished, and the ones which will be of the greatest value to him if his future work is directly connected with ore-deposits. As Mr. Stewart says, "Any attempt to learn the geology of the important mining districts of this country in a three-hour undergraduate course can leave in the mind of the average student only a few facts, often fragmentary and disjointed, and confessedly unreliable." Moreover, after studying descriptions of twenty or thirty different mining camps, with none of which he is personally familiar, the student will almost inevitably confuse the facts more or less between one case and another.

Perhaps the best contribution that I can make to the discussion for which Mr. Stewart asked is an outline of the course in economic geology which I am at present giving, as this represents my own tentative solution of the problem, under existing conditions here. The first half of the year is devoted to a brief consideration of the subject from the usual standpoint, of which Ries' textbook may be considered illustrative. The half year, however, proves all too short, even for this. During the second

semester a somewhat different course is being given, comprising chiefly a consideration of general facts and principles, and including the following topics—treated briefly, of necessity, in a three-hour course:

Terms of importance in economic geology and their definition.

Methods for constructing underground contours.

The determination of gains and losses in altered rocks, from analyses.

The classification of ore-deposits.

Common classes of ore-deposits and criteria for their recognition and discrimination, with illustrations from important mining camps.

Discussion of some of the more important papers dealing with different types of ore-deposits.

The genesis of ore-deposits, and discussion of some of the more important papers on this subject.

Enrichments in ore-deposits (including secondary enrichments, ore shoots, etc.).

The structural features of ore-deposits (including the varied effects of faulting), and their recognition.

The common modes of occurrence of different ores.

The field examination of ore-deposits.

The course also includes actual examination of hand specimens and microscopic thin sections illustrative of ore deposition.

The summer field work, in connection with the course in field geology, serves also to supplement the course in economic geology, as the work is done in the vicinity of one of the more important mining camps of this state—at Goldfield in 1910, Yerington in 1911—and includes, in addition to geologic mapping, such examination of the ore bodies as there is time for.

W. S. Tangier Smith.

REVIEWS

Development of the World's Iron Resources. By Dr. Arthur Selwyn-Brown. The Engineering Magazine. October, pp. 41–46, and November, 1911, pp. 213–232.

Rarely does it fall to a reviewer to criticize a paper which comes so near being a complete comedy of errors, as this by Dr. Brown, which apparently has been written with the avowed purpose of proving the iron resources of the world to be inexhaustible. Were it not for the fact that the article appears in a reputable magazine with editorial sanction and comment, it would be futile to point out its errors.

The Dominion Steel Company's deposit on Belle Isle, Newfoundland, is described by Dr. Brown as being 9 feet in width and extending nearly 50 miles out to sea, and probably containing 4,258,000,000 tons of iron ore of the finest quality. It would be interesting to know how Dr. Brown knows that these beds extend nearly 50 miles to sea. If true, it is larger than the tonnage of available iron ore of the Lake Superior region.

His comment on the existence of extensive deposits of iron ore on the Nastapoka islands of Hudson's Bay, appears to be an entirely unconfirmed assertion. His description of an iron-bearing belt of rocks with large and rich iron ore deposits extending from the south of Hudson's Bay down through Labrador into Newfoundland seems to be unsupported by geologic evidence, and is hardly reconcilable with the nearly identical latitude of the south of Hudson's Bay and northern Newfoundland. He regards the Matawin deposits, north of Thunder Bay, as the most important reserves of Ontario and says that they resemble closely the Lake Superior deposits of the United States and while leaner, are probably more extensive. The fact is that so far as known they are lean, banded iron-bearing cherts of Archean age with a very doubtful chance for local concentration.

"Canada is divided into nine provinces, and iron deposits of commercial importance have been discovered in all of them. Iron ores have been found in workable quantities in the islands of the Atlantic and Pacific Coasts, in Hudson's Bay, and in the frozen northlands around Bering and Baffin Seas." While there is possibility or even probability that Canada may develop valuable and extensive iron ore deposits in the future, Dr. Brown's statements give a very misleading view of the

present situation. The inferiority of the iron resources of Canada to those of the United States is generally conceded. More than three-fourths of the iron ore used in her furnaces has been imported from Newfoundland and the United States, and there is little reason to expect this proportion of imported ore to domestic production to decrease. The total production to date of Canadian iron ore amounts to about 6,000,000 short tons while the Lake Superior region of the United States alone has produced more than 452,103,186 long tons of iron ore. The grade of the Canadian ores is also inferior to those of the United States. About one fourth of the Canadian ores which are being mined consists of lean, refractory magnetites, most of which are high in sulphur, and phosphorus. In the United States, the magnetite ores constitute only about one twentieth of the total production.

Titaniferous iron ores, says Dr. Brown, are mostly "hematites" which have had part of their iron replaced by titanium, and adds that the most important deposits are in Labrador, Alaska, and Newfoundland, but that in the United States the known deposits exceed 200,000,000 tons.

The iron mines in the Lake Superior region of the United States are described by Dr. Brown as being on "mountain ranges." He says further, "The iron-bearing formations in the ranges are chiefly siliceous schists of Huronian age that are considerably folded. The folds pitch eastward and westward. The ore occurs as specular hematite interbedded with bands of jasper. The iron is contained in the schists, quartzites and other rocks as fillings between rock bedding and in the troughs of the folds. When such folds are near the surface, the ore is mined by surface stripping and open quarrying with steam shovels." This inaccurate and inadequate statement of the occurrence of the ores of the Lake Superior region is followed by a table which claims to show the tonnage of prospected and unprospected ore. The figures are obviously taken from the report of the National Conservation Commission without due acknowledgment. The headings prospected and unprospected tonnage have been put in place of available and non-available of the original report. It is scarcely necessary to remark that "non-available" and "unprospected" are not synonymous. He concludes that the supply of merchantable Lake Superior iron ore will last almost indefinitely since the annual production amounts to "nearly 2,000,000 tons."

In stating that the Mississippi valley iron deposits contain about 80,000,000 tons of ore, evidently no distinction is made between available and non-available ores.

It is obvious that Dr. Brown does not distinguish between iron-bearing rocks and iron ores, between materials of commercial grade and those which may or may not reach a commercial grade in the future, but classes all or nearly all iron-bearing rocks as iron ores.

The Graphical Solution of Fault Problems. By C. F. TOLMAN, JR. Mining and Scientific Press, San Francisco, and the Mining Magazine, London, 1911, pp. 43.

The discussions of fault nomenclature in the first volume of this journal emphasized the fact which geologists and mining engineers realize, but which, so far, has found little recognition in geological text-books, namely, that the movement on a fault may be in any direction and that the resulting dislocations of the strata, or of veins, may be very confusing. The determination from observation of the simple movements up and down a fault plane are easy, but when the movement has a component parallel to the strike of the fault the solution of the problem is much more complicated, and in only one other paper, so far as the reviewer knows, have general methods for its solution been given.[1] The methods given in these two publications are almost identical, but were evidently developed independently.

The old nomenclature of faults is inadequate to the more general conception of fault movements, and Professor Tolman begins by giving a new system of nomenclature suitable for his purposes.

The determination of the movement on the fault surface is made by observations of the dip and strike of strata, veins or other surfaces, on opposite sides of the fault and, where possible, of the position of the fault surface itself. The problem is essentially geometric and as we must deal with space of three dimensions, some method of projection is necessary to represent the conditions. Professor Tolman has selected two systems of projection. The isometric and contour systems. The former is used to give a picture of the positions of faulted strata, but the latter only for working out the problems. The contour system of projection is extremely simple. It is the method used in ordinary contour maps and its application to fault problems could be very quickly mastered by a geologist or mining engineer. Professor Tolman solves a number of problems by this method and with a little practice one can quickly learn to apply it to new problems.

There are two classes of fault movements considered; namely, those in which one side moves without rotation and those in which rotation occurs. The former are, of course, the simpler, and the problems solved show how the outcrop of the strata on different sides of the fault is dislocated by different kinds of fault movements. Professor Tolman only considers one kind of rotation; namely, that in which the axis is at right angles to the fault plane. He mentions as special examples of this kind of faulting certain regions in southern Arizona. He looks upon the more general case of rotation with translation in the direction of the

[1] "Geometry of Faults. Additional note on Geometry of Faults," Bull. G. S. A., 1909, Vol. 20, pp. 171–196, and 1910, Vol. 21, pp. 737–740.

axis as artificial; but it must not be forgotten that we are dealing with a subject which is still very incompletely studied and we should keep our minds open to the most general kind of movement possible and learn by observation what actually occurs in nature.

The contour system of projection is certainly the simplest system available, and the general geometric methods used in this book for solving fault problems are probably as simple as could be devised. Professor Tolman presents these methods very well, although the text seems a little more concise than is necessary, and the general solution of the problem of rotation might be made more simple. Professor Tolman prefers to use the word "pole" rather than "axis," and in some cases a little confusion is introduced by using the word "perpendicular" in place of "vertical," as in problems 6 and 13.

This little book can be recommended to geologists and engineers, who are concerned with fault movements; a mastery of the methods presented will greatly increase their power of dealing with fault problems.

HARRY FIELDING REID.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

ADOLPH KNOPF AND J. B. UMPLEBY.

METALLIFEROUS DEPOSITS.

COPPER.

Die Genetischen Verhältnisse der Kupfererz-vorkommen von Otavi. By P. KRUSCH. Zeit. deut. geol. Gessell., Vol. 63, 1911, pp. 240–263.

The largest ore body is at Tsumeb, German Southwest Africa; the production for the year 1909–1910 was 33,500 tons carrying 16 per cent. Cu, 26 per cent. Pb, and 0.028 per cent. Ag. The ore body lies along the contact of dolomite and aplite; the primary ore consisted of galena, sphalerite, and pyrite. These minerals have been largely replaced by chalcocite, which has also replaced dolomite and aplite by a process termed cementation metasomatism. The primary ore body was thus enormously increased in size. Later than the main chalcocitization the ore body was intruded by kersantite dikes, in part now wholly replaced by malachite and azurite.

GOLD AND SILVER.

Die Fortschritte der Gold Aufbereitung und ihre Beziehung zur Lagerstättenlehre. By C. MINNICH. Zeit. pr. Geol., 1911, pp. 432–466.

Geology and Ore Deposits of Myers Creek and Oroville—Nighthawk Mining Districts. By JOSEPH B. UMPLEBY. Wash. Geol. Survey, Bull. No. 5, 1911, 111 pages.

Cheesaw district contains noteworthy contact metamorphic deposits of copper. Near Oroville disseminated copper deposits occur unlike those of the Southwestern States, but secondary enrichment is negligible. U.

The Oaks and Eastern Portion of the Etheridge Gold Fields. By E. O. MARKS. Geol. Surv. Queensland, Pub. No. 234, 1911, 30 pages.

Describes general geology, auriferous deposits and copper deposits. U.

The Position on the Comstock. By GEORGE J. YOUNG. Eng. and Min. Jour., Jan. 20, 1912, pp. 167–173.

Reviews present conditions of mining at Virginia City which has taken on new life since the discovery of high-grade ore in the Mexican mine. U.

The Silver Fields of Nipissing. By R. E. HORE. Quart. Bull. Canad. Min. Inst. No. 17, 1911, pp. 81–106.

Gives general geology, structure, composition and genesis of ores, and commercial considerations.

The Surinam Gold Industry, Guiana. By J. H. VERLOOP. Amsterdam, Q. H. De Bussy, 1911, pp. 106.

Describes the gold-bearing reefs and placers, and the general geology of the area. Deals at length with the problem of handling the massive clay which overlies the placer gold. U.

Viagens a Matto Grosso. By L. C. FERRAZ. Annaes da Escola de Minas de Ouro Preto, No. 11, 1909, pp. 55–106.

Alluvial deposits containing gold and diamonds in commercial quantities occur in the streams of Matto Grosso, Brazil. Three dredges have been operating, but have not been particularly successful owing to managerial incompetence; the diamonds in fact, although of unusual brilliance and crystallization, were lost in the tailings.

IRON.

Beiträge zur Kenntnis der Manganerzlagerstatten in der Spanischen Provinz Huelva. By K. G. HOYER. Zeit. pr. Geol., 1911, pp. 407–431.

The deposits consist of manganese carbonate and silicate with red jasper in lenses concordantly instratified with clay slates and porphyroids and associated with diabase effusives. Are probably of syngenetic origin.

Existence de Restes Organiques dans les Roches Ferrugineuses Associees aux Minerais de Fer Huroniens des Etats Unis. By L. CAYEUX. Compt. rend., Vol. 153, pp. 910–912, 1911.

Cayeux has discovered organic remains in the iron-bearing formations of Mesabi, Menominee, and Penokee-Gogebic. Concludes that organic activity was already great during the Huronian epoch in the Lake Superior region. The fauna, instead of being primitive, is represented by organisms as high in the animal kingdom as echinoderms.

The Iron Ore Deposits of Piedmont, Italy. By R. CATANI. Jour. of Iron and Steel Inst., London, 1911, Vol. 84, pp. 355–364.

Describes briefly the mines of Traversella and Cogne both of which were probably worked in the middle ages. The average iron content

of the former ores is 49 per cent. and of the latter 66 per cent. The Traversella deposits occur along a contact of diorite and mica schist; those of Cogne in serpentine and calcareous schists near it. U.

The Iron Ore Deposits of Sardinia. By S. TESTA. J. I. and S. Inst., 1911, Vol. 84, pp. 364–380.

Sardinia is an island rich in mineral wealth but only within the past two years have its iron deposits come to be considered of commercial importance. The deposits occur along the contacts of granite with schist and limestone. U.

The Iron Mines of the Island of Elba. By CELSO CAPACCI. J. I. and S. Inst., 1911, Vol. 84, pp. 412–450.

These great iron mines are thought to date from Phœnician times. They consist of vast impregnations in the rocks of the eastern coast, especially in the Trias and Eocene limestones. U.

Minerios de Ferro no Brasil, Principalmente no Estado de Minas Geraes. By J. C. DA COSTA SENA. Annaes da Escola de Minas de Ouro Preto, No. 10, 1908, pp. 19–34.

Discusses the iron ores of Brazil, giving tonnage estimates and commercial analyses.

Reconocimiento de Algunos Criaderos de Fierro del Estado de Oaxaca. By Y. S. BONILLAS. Parergones Inst. Geol. Mexico, Vol. 3, 1911, pp. 499–524.

Western Portion of Torbrook Iron Ore Deposits, Nova Scotia. By HOWELLS FRICHETTE. Canada Dept. of Mines. Bull. No. 7, Ottawa, 1912, 20 pp.

Describes the deposits, presents the result of magnetometric surveys, and gives analyses of the ore. U.

LEAD AND ZINC.

Burketown Mineral Field. By LIONEL C. BALL. Geol. Surv. of Queensland. Pub. No. 232, 1911, 57 pages.

Describes large low-grade deposits of lead-silver and zinc ores, as yet inadequately prospected. Lead and zinc occur in about equal amounts and accompanying them are traces of cadmium. U.

TIN.

Etude sur L'etain et L'or en Bolivie. By M. M. ARMAS. Annales des Mines, Vol. 20, 1911, pp. 149–230.

Believes that the tin ores are of pneumatolytic origin and genetically related to acidic igneous rocks; takes issue with Stelzner's theory of the origin of the Bolivian tin deposits. Gold lodes are not of great importance, but placers are thought to be destined to a brilliant future.

The Geology and Mining Industries of Ulu Pahang. By J. B. SCRIVENOR. Printed by the F. M. S. Government, Ruala Lumpur. 1911. 61 pages.

Describes gold deposits which, although once productive, have recently proven disappointing. The tin deposits are also described. These are more encouraging, although it is the opinion of the writer that they have been largely worked out. Accompanying the report is a geologic map of this part of the Federated Malay States. U.

Report on the Administration of the Mines Department and on the Mining Industries for the year 1910. Malay States, Federated. Mines Dept. 1911. 13 pages.

The total output of tin amounted to 49,126.55 short tons. Wolfram was produced to the amount of 105.05 short tons. The total gold recovery was 16,767.0 ounces. U.

NON-METALLIC PRODUCTS.

COAL.

The Microscopical Examination of Coal, and its Use in Determining the Inflammable Constituents Present Therein. By JAMES LOMOX. Trans. Manchester Geol. and Min. Soc., Vol. 32, 1911, pp. 122–135.

Die Miocäne Braunkohlen Formation am Niederrhein. By G. FLIEGEL. Abh. König, preuss. Geol. Landesanst. No. 61, 1910. 78 pages, with 2 maps and 2 plates.

Gives detailed stratigraphy and discusses origin of the lignite. At one locality a 35-meter bed is quarried, an overburden of 30 meters thickness being removed. All the coal is briquetted.

Die Tropen-Sumpfflachmoor-Natur der Moore des Productiven Carbons. By H. POTONIE. Jahrb. K. Preuss. Geol. Landesanstalt fur das Jahr 1909, Vol. 30, pt. 1, 1911, pp. 389–443.

The flora of the productive portion of the Carboniferous possessed ecologic features similar to those of present-day tropical swamps.

GRAPHITE.

The Amherst (Quebec) Graphite Deposits. By FRITZ CIRKEL. Quart. Bull. Can. Min. Inst., No. 17, 1911, pp. 107–115.

OIL AND GAS.

Advance Chapter from Contributions to Economic Geology, 1910. Bull. U. S. Geol. Survey, No. 471, Part II, A, 1912, contains the following papers:

The Compton oil pool, Kentucky, by M. J. MUNN, 9 pages.

Oil and gas development in Knox County, Ky., by M. J. MUNN, 12 pages.

The Fayette gas field, Alabama, by M. J. MUNN, 26 pages.

The Powder River oil field, Wyo., by C. H. WEGEMANN, 20 pages.

Geology of the San Juan oil field, Utah, by E. G. WOODRUFF, 29 pages.

Marsh gas along Grand River near Moab, Utah, by E. G. WOODRUFF, 1 page.

Notes on the geology and possible oil resources, of the south end of the San Joaquin Valley, Cal., by ROBERT ANDERSON, 30 pages.

Oil Fields of the Empire. By J. D. HENRY, Preface by W. H. MACGARVEY. Bradbury, Agnew & Co., London, 1910, 278 pages.

The volume includes a survey of colonial oil developments and a technical description of the oil fields of Trinidad and Newfoundland. U.

Oil Resources of Illinois with Special Reference to the Area Outside of the Southeastern Fields. By RAYMOND S. BLATCHLEY. State Geol. Survey. Bull. No. 16, 1910, Urbana, Ill. 138 pages.

In this bulletin is assembled such available information as will tend to lead future exploration to those sections of Illinois where the conditions seem particularly favorable for the accumulation of oil and gas. U.

The Relationship of Structure and Petrology to the Occurrence of Petroleum (with discussion). By A. BEEBY THOMPSON. The Inst. of Min. and Metallurgy. Twentieth Session 1910–1911. Pp. 215–269.

Recognizes that petroleum is genetically related to both igneous and sedimentary rocks but emphasizes the fact that all the important sources have no direct connection with the igneous rocks. U.

PHOSPHATES.

Zur Frage über die Mineralogische Natur der Russischen Phosphorite. By W. TSCHIRWINSKY. Neues Jahrb. Min., Geol., Pal., Vol. 2, 1911, pp. 51–75, with 2 plates.

This paper gives the results of a concurrent chemical and optical study of the Russian phosphorites. It is concluded that they are not amorphous, but are cryptocrystalline, and that on the basis of the chemical character of the cement are divisible into 5 groups.

Die Phosphatlagerstätten bei Es-Salt im Ost-Jordan Lande. By P. KRUSCH. Zeit. pr. Geol., 1911, pp. 397–406.

Gives description, chemical analyses, and genesis of phosphate deposits of Palestine, which is said to be one of the richest phosphate regions of the world.

RARE EARTHS.

Monasita. By MORAVIA JUNIOR. Annaes da Escola de Minas de Ouro Preto, No. 11, 1909, pp. 37–44.

Discusses the monazite deposits of Brazil, and the extraction and treatment of the ores.

SALINES.

Beitrag zur Petrographischen Kenntnis der Salzerlagerstätte von Glückauf-Sondershausen. By M. NAUMANN. Neues Jahrb. Beilage-Band, Vol. 32, 1911, pp. 578–626.

The saliferous horizon consists of interstratified rock salt and anhydrite, including a 14-meter bed of hartsalt (anhydritic or kieseritic sylvine halite). The basal member is a 49-meter bed of rock salt; on this rests the potash bed, which in places contains a carnallite conglomerate, consisting of rolled fragments of halite, hartsalt, etc., in a carnallite matrix. This remarkable conglomerate attains a maximum thickness of 30 meters and rests on an erosion surface of rock salt and hartsalt. The salt rocks are described in detail from studies made according to the petrographic methods employed in silicate rocks.

Ergebnisse der Untersuchung von Bohrproben aus den seit 1904 im Gange befindlichen, zur Aufsuchung von Steinsalz und Kalisalzen ausgeführten Tiefbohrungen im Tertiär des Oberelsass. By B. FÖRSTER. Mitteil. der Geol. Landesanst. von Elsass-Lothringen, Vol. 7, 1911, pp. 349–524, with map and 4 plates.

The sylvinite deposit of the Wittelsheim basin in Upper Alsace is estimated to contain 300,000,000 tons pure K_2O. This alone would be sufficient to supply the world's demand for 493 years.

Potash-Bearing Rocks of the Leucite Hills, Sweetwater County, Wyoming. By A. R. SCHULTZ and WHITMAN CROSS. Bull. U. S. Geol. Survey, No. 512, 1912, 39 pages.

It is estimated that the available leucite-bearing rock aggregates 1,973 million tons, which contains 197 million tons K_2O and 197 million tons Al_2O_3.

REGIONAL.

Apuntes sobre la Distribucion de Minerales en el Estado de Durango. By N. RANGEL. Bol. Soc. Geol. Mex., Vol. 7, 1911, pp. 105–123.

Estudio Geologico y Minero de la Sierra de el Oro, Durango. By L. V. ROLDAN. Bol. Soc. Geol. Mex., Vol. 7, 1911, pp. 125–134.

Die Erzlagerstätten des Fürstentums Waldeck. By K. MASLING. Zeit. pr. Geol., 1911, pp. 361–377.

The ore deposits include those of gold, copper, iron, manganese, lead, and zinc. The iron ores are worked in a small way. The copper deposits resemble those of Mansfeld; they form a bedded deposit in the Zechstein and the richness of mineralization in the ore-bearing bed is determined by the presence of fissures that intersect it.

Persien. By A. F. STAHL. Handbuch der Regionalen Geologie, Vol. 5, No. 6, 46 pages, with 2 plates. Heidelberg, 1911.

Gives the general geology and orography of Persia, and description of the occurrence of commercially valuable minerals. Persia is rich in various useful minerals, which apparently have been but partly discovered and only superficially exploited. A bibliography is appended.

The Sitka Mining District, Alaska. By ADOLPH KNOPF. Bull. U. S. Geol. Survey, No. 504, 1912, 32 pages.

The mineral resources are gold and gypsum. The gold occurs in quartz lodes occupying shear zones in graywacke. The ores at the productive mines range from $15 to $90 a ton, contrasting notably with the $2.78 average for the ores of southeastern Alaska.

GENERAL.

Classification Metallogenique de Corps Simples. By L. DE LAUNAY. Rev. gen. sci., 22, 1911, pp. 633–644.

An empirical classification designed to show the natural metallogenetic associations of the elements.

The History of Gold Mining in the United States. By R. A. F. PENROSE, JR. Pop. Sci. Month., Vol. 80, 1912, pp. 174–190.

Concludes with the prognosis that for a long time to come the present production of $100,000,000 yearly should easily be maintained.

UNCLASSIFIED.

Crystallized Variscite from Utah. By W. T. SCHALLER. Proc. U. S. Nat. Mus., Vol. 41, Jan. 31, 1912, pp. 413–430.

Outlines occurrence, optical properties, crystallization, and composition. U.

The Recognition of Minerals. By C. G. MOOR. The Mining Journal, London, 1909, 247 pages.

The book comprises "a collection of notes and simple tests for the use of travelers and prospectors," and includes a short account of the compounds and uses of each separate element. U.

The World's Minerals. By LEONARD J. SPENCER. W. & R. Chambers, Ltd., London, 1911, 212 pages, 40 colored plates, 21 diagrams.

Describes 116 more common mineral species and illustrates 163 figures on colored plates. U.

SCIENTIFIC NOTES AND NEWS[1]

H. S. GALE returned to Washington in the middle of April, after spending three months on the Pacific Slope, principally in Idaho and California.

B. S. BUTLER, of the U. S. Geological Survey, left Washington April 25 to begin geologic field work in Utah.

W. C. PHALEN, of the U. S. Geological Survey, was in St. Clair County, Ala., and Chattooga County, Ga., early in April, examining deposits of halloysite and wavellite.

A. C. VEATCH, consulting geologist, specializing in oil, has been in the California oil fields for the past three months.

A. G. MADDREN, of the Alaska Division of the U. S. Geological Survey, left Washington the last week in April bound for Seattle. He is on his way to the Upper Porcupine River, for the purpose of completing during the coming summer a geologic examination of the international boundary from the Porcupine to the Arctic coast.

J. B. TYRRELL, of Toronto, is to head the Ontario Government Expedition to locate the five-mile strip which the province is to receive from the Dominion. His party, consisting of one or two surveyors and a half-dozen Indians, will probably proceed to Winnipeg the last of May, and thence by Lake Winnipeg to Port Nelson. A large part of five months will be spent along Hudson Bay. Mr. Tyrrell has personal knowledge of the Hudson Bay district, which will make his services of especial value.

AT THE MEETING of the National Academy of Sciences, held in Washington April 18, among other scientists, the following geologists were elected to membership: Harry Fielding Reid,

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Johns Hopkins University, and David White, U. S. Geological Survey.

D. F. MACDONALD, geologist to the Isthmian Canal Commission, has been granted three months' leave of absence from his duties with the commission, to make a geological study of the disputed territory between the republics of Panama and Costa Rica. He sailed from Colon for Bocas del Toro, near the Costa Rican border, on April 1; from there, he will proceed by small boat with native porters to the region to be examined.

T. A. RICKARD, editor of the *Mining Magazine,* recently came from London and delivered a series of lectures to the students of McGill University on the "Valuation of Mines." He later attended the meeting of the Canadian Mining Institute recently held in Toronto, where he delivered an address upon the same subject to the members of the institute. He then left for San Francisco, visiting New York in April on his way back to London.

W. S. TANGIER SMITH, member of the United States Geological Survey, 1900–1905, and head of the Department of Geology and Mineralogy, University of Nevada, 1906–1912, is practicing as a consulting geologist with offices at 155 University Terrace, Reno, Nevada.

WALDEMAR LINDGREN, chief of the Division of Mineral Resources, United States Geological Survey, delivered a lecture before the Mining Society of Sheffield Scientific School, Yale University, Tuesday, April 23, on "California Gravels." The lecture was illustrated by lantern slides.

L. D. MOORE AND N. P. TURNER have formed a partnership to take up general engineering and exploration work, specializing in the West Indies, Central and South America.

WARREN D. SMITH, chief of the Division of Mines, Bureau of Science, Manila, is spending a leave of absence in the United States, during which he expects to make a study of the oil fields of California. On his return to the Philippines, he will take charge of a survey of the Tayabao oil field in S. E. Luzon. His

address until about October 1, 1912, will be C/o Prof. Charles Forster Smith, 1715 Kendall Ave., Madison, Wis.

WALTER HARVEY WEED AND FRANK H. PROBERT announce that the firm of Weed & Probert has been dissolved by mutual consent. Mr. Weed will continue in practice as consulting engineer and mining geologist with headquarters 42 Broadway, New York. Mr. Probert will continue in practice as consulting engineer and mining geologist with headquarters Suite 314, Central Building, Los Angeles, California.

CHARLES H. SHAMEL is working on a new edition of his "Mining, Mineral and Geological Law," and requests all readers of ECONOMIC GEOLOGY to give him the benefit of any corrections or suggestions as to changes, additions, etc., which would render the book more useful. He is especially desirous to have examples of the use of geology or allied sciences or geological evidence in other than mining litigation, and in this he particularly includes such cases as may *not* have been appealed to the higher courts and reported in the printed decisions. Address C/o his publishers, McGraw-Hill Book Company, 239 West 39th St., New York City.

FRANK D. ADAMS, of McGill University, delivered a series of five lectures during March on the subject of "Rock Flowage" to the students of the Department of Geology of the University of Wisconsin. He also addressed the Science Club on "Ancient and Modern Conceptions of the World."

THE DIVISION OF MINES of the Bureau of Science, Manila, has just issued four new reports: "The Geology of the Aroroy District of Masbate," by H. G. Ferguson (map); "The Geological Reconnaissance of Mindanao, Part III., Geology," by Warren D. Smith (map); "Geological Reconnaissance of Southeastern Luzon," by G. I. Adams and Wallace S. Pratt (map); "Additional Notes on the Economic Geology of the Baguio Mineral District," by Warren D. Smith and Frank T. Eddingfield (map).

THE GEOLOGICAL SOCIETY OF AMERICA, Cordilleran Section, held its thirteenth annual meeting at Stanford University, Cali-

fornia, on April 5. Papers were presented by N. F. Drake, Bruce Martin, Austin F. Rogers, G. E. Postma, J. C. Branner, E. C. Templeton, J. Claude Jones, George D. Louderback, Robert W. Moran, Andrew C. Lawson and J. C. Hawver.

THE WEST VIRGINIA GEOLOGICAL SURVEY has issued a new publication entitled "Detailed County Report on Jackson, Mason and Putnam Counties," under date of December 15, 1911.

THE TENNESSEE ACADEMY OF SCIENCE is a new organization which promises to take a prominent place among like organizations throughout the country. At a meeting held in Nashville recently a constitution was adopted and steps taken to hold an initial meeting in April. At this meeting in addition to a regular program the officers of the academy were to be elected and steps taken to extend the membership so as to include all white persons in the state who are interested in any phase of science or cognate subjects. Meetings are to be held annually on the Friday following Thanksgiving. For the present the movement centers in the office of the State Geologist at Nashville.